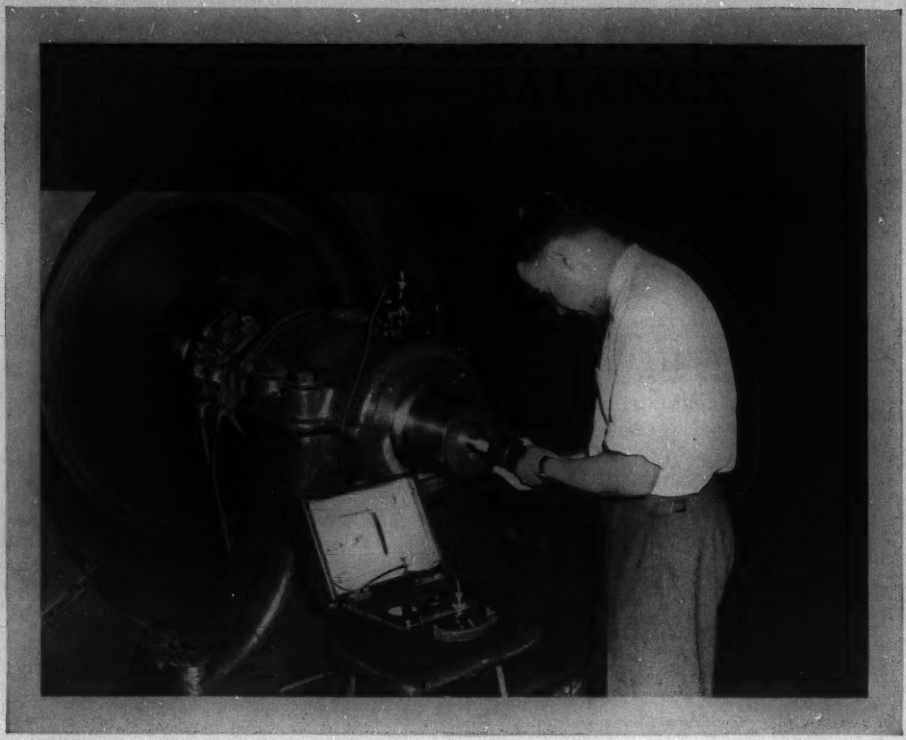
# Electrical Engineering

June
1940

AIEE Summer Convention, Swampscott, Mass., June 24-28, 1940



HOW simple would you say it is to balance a 50-ton alternator rotor moving at 3600 rpm until its vibration is less than three ten-thousandths of an inch—or one-tenth the diameter of a human hair? Not very, you say? Well, a little while ago you may have been right. Today you're wrong.

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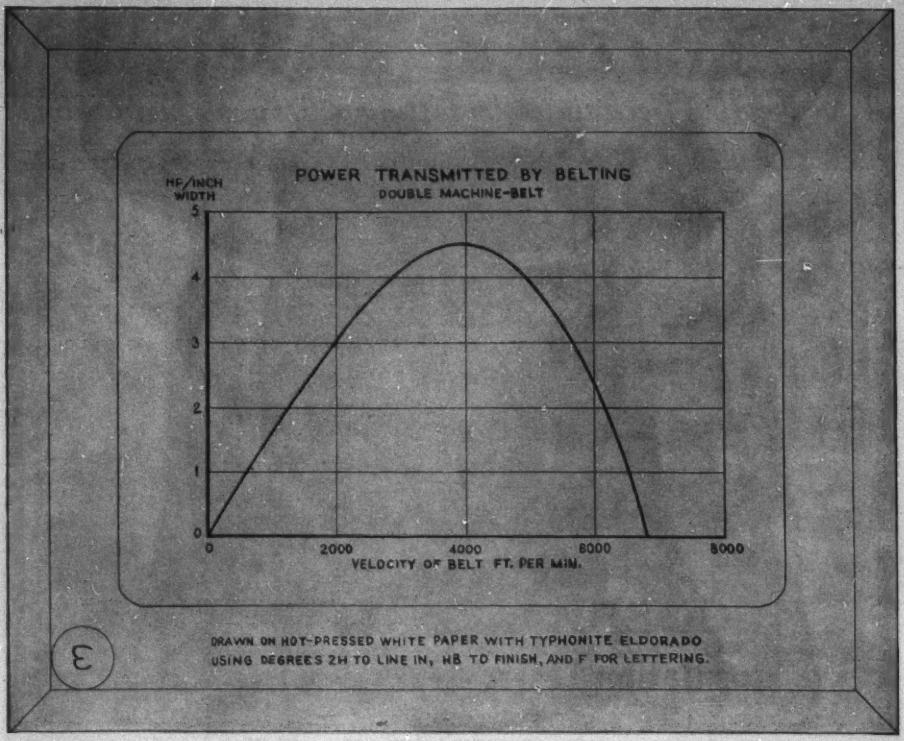


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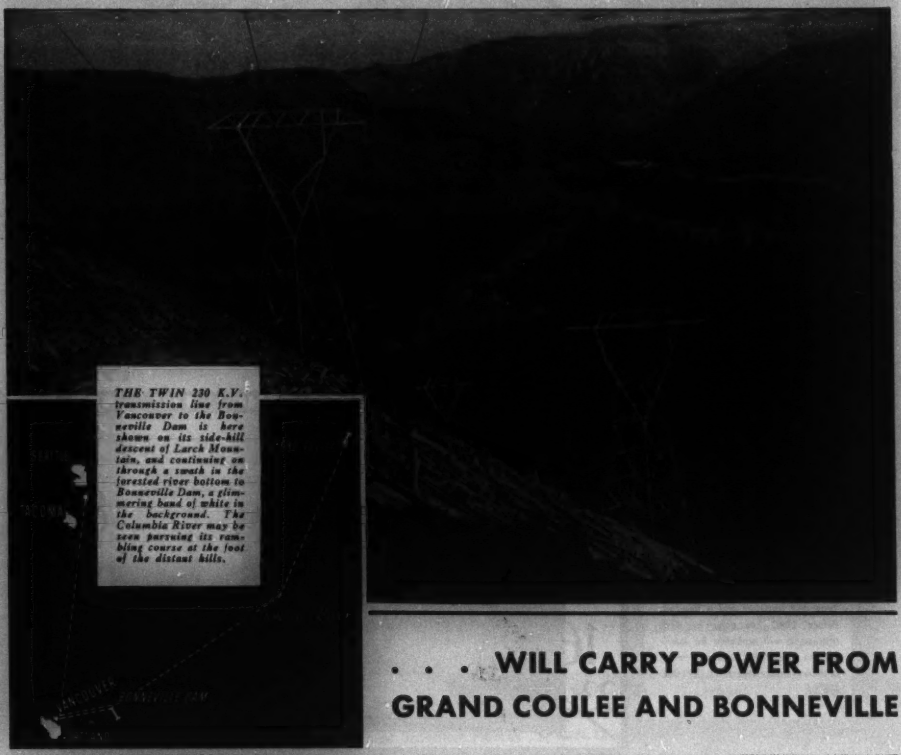

*THE TWIN 230 K.V. transmission line from Vancouver to the Bonneville Dam is here shown on its side-hill descent of Larch Mountain, and continuing on through a swath in the forested river bottom to Bonneville Dam, a glimmering band of white in the background. The Columbia River may be seen pursuing its rambling course at the foot of the distant hills.*

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# 25 YEARS AGO

**1915** - *SKIN-EFFECT RESISTANCE MEASUREMENTS OF CONDUCTORS at radio frequencies up to 100,000 cycles per second. During 1915–1916 important research on this problem was undertaken at one of the leading educational institutions with the equipment shown—the latest then available. Included in the set-up are an Alexanderson r-f alternator delivering 2 kw at 100,000 cycles, a hot-wire ammeter, adjustable paper condenser, variable air condenser, fixed telephone condenser, single slide-wire, fixed and adjustable inductances, a portable galvanometer, a headset and 1,000-cycle commutator interrupter. These instruments represented the latest developments in the instrumentation field in 1915.*

**1940** - *TWENTY-FIVE YEARS LATER the same measurements can be duplicated with this equipment at frequencies up to 1,000,000 cycles per second and with accuracies far in excess of those possible in 1915. Included are General Radio Type 516-C Radio Frequency Bridge, Type 684-A Modulated Oscillator, Type 619-E Heterodyne Detector, Type 663 Resistors and a headset. Before 1940 has gone by G-R instruments will probably be available to extend the frequency range of these measurements to 10,000,000 cycles!*

● **GENERAL RADIO COMPANY** celebrates its 25th Anniversary this month. The twenty-fifth year in the life of most companies or persons is not particularly significant; but in the radio and electronic measuring-apparatus field twenty-five years takes one practically back to the beginning. General Radio is probably the oldest company of its kind in the world. It has been continuously engaged (under the same name, with the same directing head and with the same managerial policy) in the design, manufacture and sale of precision electrical laboratory apparatus for use at communication frequencies. General Radio instruments have always kept abreast of the developments in the electronic art and its apparatus has in no small measure contributed to the ease with which further developments have been and are possible.

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# Electrical Engineering

Registered U. S. Patent Office

## for June 1940—

**The Cover:** The New Ocean House at Swampscott, Mass., headquarters for the 1940 AIEE summer convention, June 24–28.


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# High Lights • •

**Culture in Engineering.** Culture must develop mental flexibility, a sympathy with the viewpoint of people of divergent interest, and an understanding of where one's own vocation fits into the interest of the society to which it is at the most only ancillary. This is one of the thoughts expressed by an AIEE past president in discussing the general subject (*pages 229–31*).

**Trends in Electric-Power Apparatus.** Much of the development in electrical apparatus can be traced to research and to the close co-operation between manufacturers and users who have had the courage to try new and promising ideas, according to an engineer of one of the larger manufacturers (*pages 221–6*).

**Engineers and Unionization.** Whether or not an engineer shall join a union is a question that each individual must answer for himself, but engineers who develop habits of thinking in connection with their work as prescribed by the union code would be in grave danger of self-disqualification as professional men, in the opinion of one prominent AIEE member (*pages 227–8*).

**Contact Phenomena.** The closing and opening of contacts carrying weak currents, such as those in telephone switching circuits, involves the generation of high-frequency transients that may eventually cause erosion of the contact metal because of the many operations that are made during the life of the contact, even though the duration of the phenomena may be only a few microseconds at each operation (*Transactions pages 360–8*).

**Local AIEE Activities.** The annual report on AIEE Section and Branch activities for the fiscal year just ended shows that three new Sections were organized and one new Branch authorized during the year, making a total of 70 Sections and 121 Branches. During the year the attendance at 701 Section meetings and 1,346 Branch meetings totaled 91,949 and 64,972, respectively (*pages 250–3*).

**Temperature Rise.** Electrical apparatus exposed to the sun's rays may have an additional temperature rise of as much as 20 degrees centigrade, but a wind velocity of a few miles per hour may compensate for this by increasing cooling by convection (*Transactions pages 338–45*).

**Arc-Backs.** Studies of arc-backs in mercury-arc rectifier tubes by an oscillograph with a "memory" indicate that arc-backs may occur throughout the whole inverse period rather than only at the transition from the normal conducting to the normal insulating state (*Transactions pages 345–7*).

**Summer Convention.** Ten technical sessions, one general session, and seven technical conferences comprise the scheduled technical program of the AIEE 1940 summer convention to be held at Swampscott, Mass., June 24–28. The summer convention committee is endeavoring to take full advantage of the location by providing ample opportunity for sports and recreation (*pages 248–50*).

**Suburban Power Supply.** Increased capacity to meet a growing load was provided on the suburban power supply system of a large eastern metropolitan power company by raising primary voltage from 13 kv to 33 kv. Single-line single-transformer-bank substations are used in lightly loaded areas, including many pole-type and factory-assembled substations (*pages 234–8*).

**High-Voltage Laboratory.** Scheduled functions of the new high-voltage laboratory of the National Bureau of Standards include: X-ray and nuclear-physics studies; precise calibration of voltage transformers; testing of insulating materials; and research and development on methods of measurement at high voltages (*pages 238–40*).

**Room Noise.** Supplementing the results previously reported in ELECTRICAL ENGINEERING, an article in this issue reports additional data obtained on a continued survey of room noise at various types of locations (*pages 232–4*).

**Response Indicator.** A new indicator for the performance characteristics of communication circuits shows the change of phase angle between input and output voltages, as well as the change in magnitude, by the shape of patterns on the screen of a cathode-ray tube (*Transactions pages 355–7*).

**Lightning Arresters.** Performance values which may be expected of present-day commercial station-type lightning arresters rated from 3 to 245 kv have been prepared by the AIEE lightning-arrester subcommittee (*Transactions pages 347–8*).

**Textile Machinery.** Tests previously reported to establish the characteristic power requirements and to derive an empirical formula for horsepower for spinning machines have been continued for a 216-spindle frame (*Transactions pages 336–8*).

**Wire Corrosion.** Fine copper wires in coils sometimes fail from what appears to be corrosion, and various causes based on inference have been suggested. Investigation now indicates that cellulose is the source of the trouble (*Transactions pages 357–60*).

**Upper-Air Soundings.** Airplanes have been supplanted by unmanned balloons for gathering meteorological data with the production of an instrument-controlled radio transmitter for relaying pressure, temperature, and humidity indications to the ground from altitudes as high as 25 kilometers (*Transactions pages 321–8*).

**Current Measurement.** Current is an essential factor in the complete specification of spot-welding conditions, but its measurement is complicated by the short duration of flow, wave shape, and other factors; a variety of proposed methods were compared in the course of a research program (*Transactions pages 349–54*).

**Lightning Protection.** Reconstruction of 60 miles of wood-pole line to use the inherent insulation of the wood together with the provision of lightning protector tubes on one of three phase wires has reduced lightning outages more than 90 per cent (*Transactions pages 328–35*).

**Correction.** In equation 3, page 189 of AIEE TRANSACTIONS (March section) a factor $n$ was omitted from the exponent of $\epsilon$. The equation should be:

$$\frac{\theta}{\phi} = 1 - \frac{\epsilon^{\frac{-2\pi n t}{T_0}}}{\sqrt{1-n^2}} \sin\left[\frac{2\pi t}{T_0}\sqrt{1-n^2} + \sin^{-1}\sqrt{1-n^2}\right]$$

**Coming Soon.** Among special articles and technical papers now undergoing preparation for early publication are: an article on the subject of the ionosphere by K. K. Darrow; an article discussing some of the current problems faced by modern rail transport by A. M. Wright (A'27); an article discussing the high-speed motion-picture camera as a tool in electromechanical design by J. R. Townsend; an article outlining a method of selecting the size of distribution transformers by M. F. Beavers (A'31); a paper on the application of traction motors by F. E. Wynne (F'20) and G. M. Woods; a paper on co-ordination of power and communication circuits for low-frequency induction by J. O'R. Coleman (M'29) and H. M. Trueblood (M'25); a paper describing a new postgraduate course in industry in high-frequency engineering by A. R. Stevenson, Jr. (F'37) and Simon Ramo; a paper on lightning currents in arresters at stations by I. W. Gross (M'40) and W. A. McMorris (M'37); a paper discussing enclosed spark gaps by W. E. Berkey (M'39); papers on the impulse strength of cable insulation by C. M. Foust (M'31) and J. A. Scott (M'34), and E. W. Davis (F'34) and W. N. Eddy (M'29); a paper on electric power for airplanes by W. J. Clardy; a paper on the accuracy of watt-hour meters on intermittent loads by M. A. Faucett (M'35), C. A. Keener (M'28), and M. S. Helm; and a paper on watt-hour meter performance with power rectifiers by C. T. Weller (M'21), H. E. Trekell (A'35), and F. O. Stebbins (M'39).

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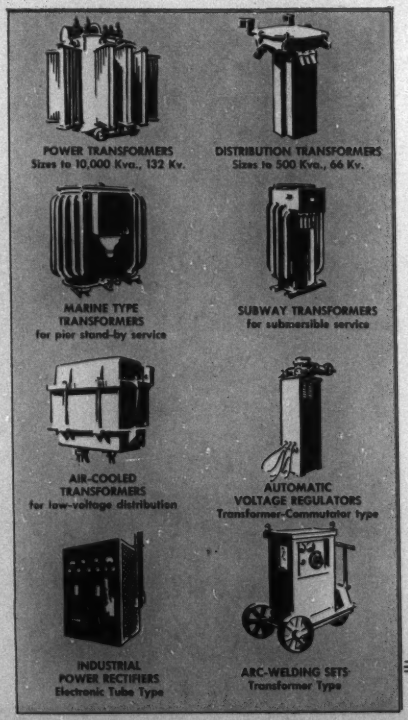


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# Trends in Electrical-Apparatus Development

A. C. MONTEITH
ASSOCIATE AIEE

***A brief survey of significant developments in apparatus for the generation, transmission, and distribution of electric energy***

DEVELOPMENTS in electrical apparatus might be compared with the saying "From the acorn comes the mighty tree." Likewise, the growth of the electrical industry can be compared with the growth of the tree into a forest. The acorn might develop into a great tree or be choked out by stronger trees or thoughts, but always the forest is increasing in coverage. When we examine the development of electrical apparatus we find a large number of thoughts that have not matured, whereas some one thought may have been the nucleus of a complete industry.

As the subject of this article, one part of the "forest" has been selected for a brief survey of the developments—the generation, transmission, and distribution of electric energy.

A Westinghouse catalog dated 1888 set forth in glowing terms the great strides that had been made in the development of generating equipment. The fact that dynamos could be offered that would supply 3,000 lights was an achievement; station switches were simple fused knife switches; and the very efficient lightning arrester consisted of nothing more than a saw-toothed gap in air. When we look back, we see that this was the start of the electrical industry. Today we have generators capable of supplying 8,000,000 lights; we have circuit breakers that will interrupt several million kilovolt-amperes in place of knife switches; and we have highly developed lightning arresters that will handle a direct stroke of lightning and clear a circuit of up to 287 kv operating voltage.

Much of the development can be traced to research and to the close co-operation of the manufacturers and users who have had the courage to try out the new and promising ideas. In a large number of cases we find the old adage "necessity is the mother of invention," has influenced some of the particular points of attack and selected some of the paths that we have followed.

## GENERATION

The necessity for more economical generation, in order to promote the industry, has meant a continuing change in power-station design, but it has certainly secured results. Thirty years ago the average coal consumed to produce a kilowatt-hour of electricity was 5.4 pounds. Twenty years ago it was 3.3 pounds, and today a modern base-load station of 100,000-kw capacity can produce a kilowatt from 0.86 pound of coal—less than one-sixth the amount used a generation ago. Many factors have contributed, some of which are, higher inlet pressures and temperatures, and larger units or combinations of units. This trend in temperatures and pressures is very strikingly illustrated in figure 1. In the 30 years mentioned, the pressure has gone from 275 to 1,250 pounds per square inch and there is now under construction a station to use 2,400 pounds. The inlet temperature has been increased from 600 to 950 degrees Fahrenheit in this time.

Great credit is due the boiler manufacturers for the tremendous advances in steam generation. Rapid strides also have been made in the increase of size and speed of turbine-driven machines. Research has made possible the building of larger 3,600-rpm machines now than were available at 1,800 rpm in 1925. Today we are building an 81,250-kva 3,600-rpm machine. All this can be attributed to developments in metals as well as the improvement in efficiency and methods of dissipating losses—all triumphs of research. Figure 2 illustrates the trend in the size of machines operated as units. An examination of the ratings of machines purchased in the last five years indicates a trend more toward smaller and higher-speed units placed closer to load centers. Some of the trend to the smaller generators might also be traced to the fact that many of them are superimposed machines. Actually, the combination of the superimposed and low pressure units sometimes results in a fairly large operating unit.

Figure 3 is an artist's conception of the 81,250-kva 3,600-rpm machine, the largest yet undertaken. It illus-

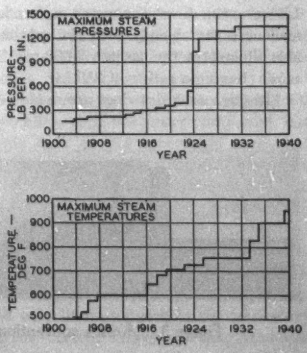


**Figure 1. Trend in maximum turbine inlet pressure and temperature**

Essential substance of a paper presented at meetings of the AIEE Philadelphia Section, October 9, 1939; Memphis Section, April 15, 1940; St. Louis Section, April 17; and Wichita Section, April 19.

A. C. MONTEITH is manager, central station engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

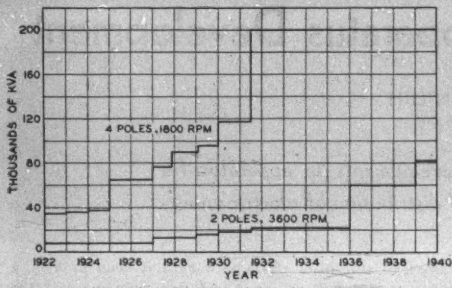


**Figure 2. Trend in maximum size of 60-cycle two- and four-pole turbine generators operating as units**

trates three trends: the increasing size of 3,600-rpm machines, already discussed; the use of hydrogen as a cooling medium; and the effort to improve appearance. The trend to hydrogen-cooled machines has been very pronounced for the larger high-speed machines. Hydrogen is a very efficient heat conductor and is lighter than air; therefore the windage losses, which are large in 3,600-rpm machines, are materially reduced. The use of hydrogen has made possible the building of generators approaching 99 per cent efficiency. In the last five years, 95 per cent of the units to which hydrogen-cooling is economically suited, have been so cooled.

The question of appearance has received the undivided attention of the manufacturer and user. In order to improve the appearance of the machine and blend the different parts into a pleasing assembly, preliminary artist's drawings are prepared for the larger machines before work is started on the final design. This gives some idea of the appearance of the completed machine when installed. Any one familiar with the earlier machines will readily see the contrast of how corners are rounded, how unsightly piping, valves, and gadgets are concealed, and how the whole is blended into a finished-looking machine. For example, the first designs of hydrogen-cooled machines had the water box of the cooler exposed as well as the connecting piping. This has been completely enclosed with a housing that blends with the lines of the main machine. Likewise the direct-connected exciter has been built in an enclosure that blends with the machine lines. Figure 3 also illustrates the largest 3,600-rpm exciter yet undertaken, having a rating of 250 kw.

Although such drawings are made and models are built of the larger machines, appearance is not overlooked in the smaller machines. In other words, we are no longer just designing a piece of apparatus to produce so many kilowatts, but we are now designing a piece of apparatus that will produce these kilowatts and also blend into a station design in a pleasing manner.

Although the improvement in efficiency of steam generation has restricted the field of economical water-power developments, there is still a demand for even larger water-wheel generating units. Figure 4 shows the trend in size of water-wheel-driven machines. The 108,000-kw Grand Coulee machines are the largest in size and rating yet undertaken. Appearance has also been improved in the design of this class of machine.

## TRANSMISSION

In all branches of the transmission of power there has been a concentrated effort to obtain a clearer and better understanding of the fundamentals. Following the World War, increased loads necessitated working existing lines to the limit. Some failed under the strain so that consideration was given to reasons and methods of overcoming the difficulties. Stability of systems became a much discussed problem, and methods were presented to calculate the performance of lines. Stability has been a much used word in connection with transmission of power, and we find many definitions in the printed matter. Although the analytical methods of calculating the performance of systems are well understood, the problem is very tedious and sometimes impossible of solution, especially with the more complicated systems having many generating stations.

At the same time that stability was a problem to the utility companies, a large number of railway networks also was being considered in the United States, and the calculations for this class of service were practically impossible. As a result of these difficulties the a-c network calculator was devised as a means of setting up systems in miniature, placing different types of faults on the system, and allowing a recording of the results of various switching operations. In other words, the system is set up in miniature and operated as the actual system would be in practice, with the pleasing advantage that faults can be applied and switches can be opened and closed at will without jeopardizing the service such as would be the case if tests were run on the actual system. This tool greatly simplified the calculations of complicated networks and made possible studies that previously could not have been undertaken. The network analyzer has been in operation

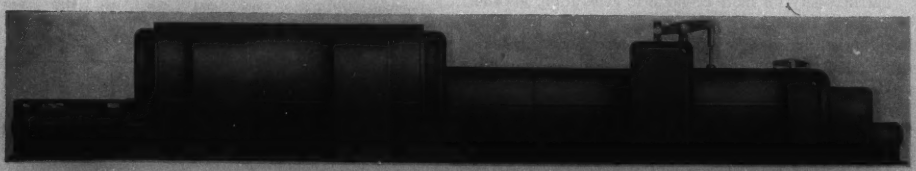

**Figure 3. Artist's conception of an 81,250-kw 3,600-rpm turbine, illustrating improved appearance**

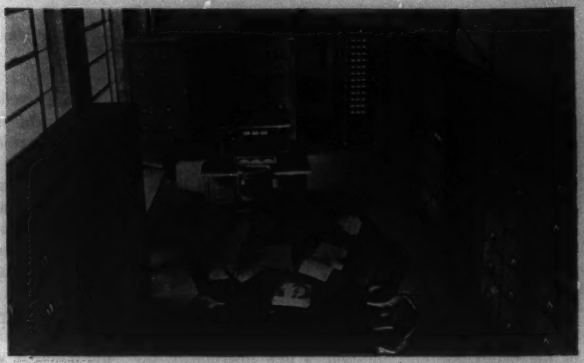

**Figure 5. The network calculator, a means of operating the planned system**

for ten years, and more than 200 systems have been studied for practically all the ailments that could possibly exist in an electrical system. The use of this calculator is now the universally accepted method of making a study on a complicated system. During the past ten years the utility of the calculator has been broadened. It has been used for new and interesting problems, one of which, the application of the De-ion protector tube, is directly connected with the transmission problem.

The De-ion protector tube is a device that is placed in parallel with line insulation. When lightning strikes the line the surge current flows through the tube instead of the insulator. At the time of breakdown the tube is virtually a short circuit on the line. To function properly it must become an insulator before the oil circuit breakers controlling the line are tripped out. We know that arcs in contact with certain materials, cause them to give deionizing gases. These try to extinguish or deionize the arc at or close to current zero. We also know that when a short circuit is applied to a system and is removed the system voltage goes to a low value and then recovers at a rate depending on system line characteristics, transformers, loads, and other factors. Whether the arc will extinguish or not depends on the rate at which the system recovery voltage tends to maintain the arc path as contrasted to the rate at which the deionizing action tends to build up dielectric strength. If the dielectric strength recovers faster, then the arc is extinguished. If the system voltage recovers faster, then the tube restrikes. Thus we have a race between these two opposing factors and the problem is to predict the results before actually running the race.

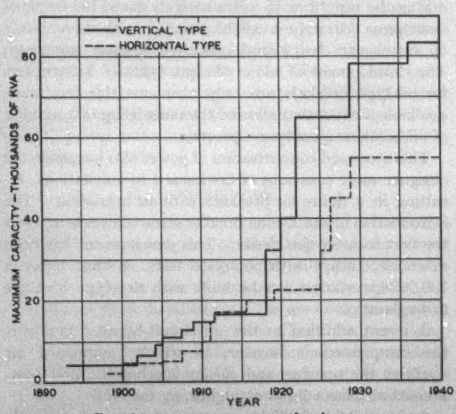


**Figure 4. Trend in maximum water-wheel generator ratings**

Laboratory tests will give the dielectric recovery of tubes, one factor in the race, but it is difficult to take a system and test it for all the possible variables to obtain a true picture of the system recovery voltage, or the other factor in the race. Here again the network calculator made possible a solution to a problem that heretofore had not been undertaken in a broad way.

The satisfactory application of the De-ion protector tube has allowed the design of lines that are practically lightningproof, and has provided a means of rehabilitating lines already built but vulnerable to lightning outages.

This raises the question as to what is our present knowledge of lightning and what we know about protecting lines and equipment against it. The desire for better service not only stimulated the extensive study of stability to provide means for better system operation under fault conditions, but also launched an intense field and laboratory study of the subject of lightning, to see if a large number of these faults could be eliminated by a better understanding of the problem. This work resulted in the direct-stroke theory which revolutionized line design. It is not a question now as to whether or not a lightningproof line can be built because there are several in operation; rather it is a question of refinements to obtain such lines at the lowest possible cost. These refinements require more information on the exact wave shape of the front and tail of the lightning stroke and its magnitude and duration. Schonland in South Africa has done some very fine work and has evolved a theory for the formation of lightning discharges. McEachron in the United States has checked some of the evidence secured by Schonland, and also, in co-operation with the power companies, has secured considerable data on the magnitude of surges. Wagner has now evolved some new instruments that have already proved their worth in securing further data. One of these that has given some very interesting data is described in the succeeding paragraph.

For many years it has been desired to secure a complete graph of magnitude and duration of lightning discharges, but little information is available. Burns on lightning-arrester gaps could only be reproduced in the laboratory by the use of long low-current surges with magnitudes of

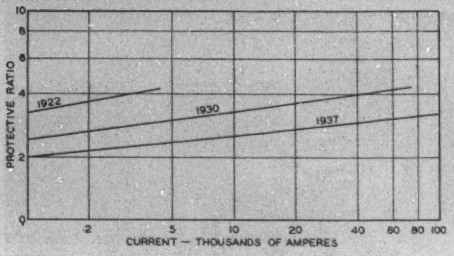


**Figure 6. Improvement in lightning-arrester protection**

the order of 2,000 to 4,000 amperes and durations up to 3,000 microseconds. In order to secure a complete story of the magnitude and duration, a new instrument, the Fulchronograph, has been built and a large number installed. This instrument has been developed primarily for the purpose of measuring the current in lightning strokes or in apparatus connected to transmission lines through which a current flows that is associated in some manner with the lightning current. Two types have been developed: One, known as the high-speed instrument, measures total intervals of time of the order of one cycle (on a 60-cycle system); the other, or slow-speed instrument, measures current variations having a duration of approximately one second. These devices are arranged to be connected into the circuit and are ready at all times to measure the current without need of tripping the circuit or throwing the switch as a motor drives them continuously. Their operation is based on the principle of storing the current indications in the form of remanent magnetism which is later measured at leisure. In this principle they are similar to the surge-crest ammeter.

A few of the outstanding conclusions from field investigations are that: currents of the order of 100,000 to 200,000 amperes can exist; the probability of surges of low magnitude is much greater than that of high-magnitude surges; long-duration surges of low magnitude can exist; there can be one or several repeated strokes in the space of a few cycles.

How has all this lightning investigation influenced the design of lines and apparatus? As a result of this work economical high-voltage lightningproof lines can be built by the proper use of ground wires. This is a reality. Lines in lower-voltage classes already built or being built have been made practically lightningproof by the application of the De-ion protector tube.

These findings have also influenced lightning-arrester design. Figure 6 shows how the protection ratio of lightning arresters has been lowered. Recognizing the possibility of having to discharge currents of high magnitude, the arresters not only have been made capable of carrying these currents but also have been designed to give protection to the apparatus. If the impulse strength of equipment had a ratio of say 4.0 then it can readily be seen that the improvement in the arrester characteristics is such that the insulation is protected against high-magnitude surge currents. Also the characteristics of arresters of the line type have been changed to be capable of discharging surges of long duration.

### STATIONS AND SUBSTATIONS

In high-voltage substation equipment there has been a trend to the use of high-speed reclosing of circuit breakers with times selected to insure maintenance of synchronism of equipment after the operation. Breakers for 132 kv are now available that can reclose a line in less than 20 cycles from the inception of a fault. The limit to which this speed can be carried is dictated by the dead time or open time to allow the arc path of the fault to deionize. On 132 kv this is of the order of 10 to 12 cycles; however, this time plus the opening time of the breaker still allows the reclosing when the operation is on a tie between two large systems. Reclosing would not be feasible when all the power is transmitted, as times shorter than this deionizing time must be secured to maintain synchronism.

Quick clearing of faults on all systems is desirable, and there have been improvements such that standard breaker clearing times are of the order of eight cycles. In order to utilize the improvement in breaker speeds, high-speed relays have become standard equipment on important lines. Relays are now available that will operate in less than one cycle for faults occurring on the greater part of a line section. They may be of the impedance type, carrier-current type where the ultimate in speed is required for long lines, or pilot-wire type for short lines.

What is the trend in circuit-interrupting devices? Circuit-breaker designs and developments are not subject to the same accuracy of refinement of calculations as are some other classes of apparatus where magnetic and electric circuits are more closely defined. Any new idea or radical departure from conventional construction must be thoroughly tried and completely tested to determine its adequacy and performance. This not only adds to the time required for major circuit-breaker developments, but also necessitates the maintenance of very large and expensive laboratory testing equipment.

The great concentration of power in the United States during the last 10 or 15 years severely taxed the forms of switchgear formerly available, and an intensive study of switchgear design and operation became necessary. The development of more efficient types of interrupters for oil-type breakers not only overcame this but made available devices that allowed the remodeling of a number of oil breakers already in operation.

This increased concentration of power also has made the designer more conscious of fire hazard in substations, resulting in a desire for breakers with air insulation. The introduction of the De-ion breaker some ten years ago was the first to meet this desire. This development has been extended, always with complete tests, so that today a 100,000-kw station can be built with dry-type breakers throughout.

A recent addition to the air-circuit-breaker family is the compressed-air breaker, in which compressed air operates the opening and closing mechanism, and compressed-air blasts aid in extinguishing the arcs.

Approximately 2,000 interrupting tests have been made

on a 1,500,000-kva breaker of this type. Single-phase interruptions have been made of currents from 1/4 ampere to 65,300 amperes, with 13.2 kv across the contacts. Cathode-ray and magnetic oscillograms have been obtained throughout the current range. All currents can be interrupted at the first zero with about one-half cycle of arcing. The low-current interruptions do not give rise to overvoltages; throughout the range of test no transient voltage greater than twice normal was observed. The high currents can be interrupted without external flame, and without objectionable noise.

There has also been a very wide acceptance of factory-built-and-assembled switchgear. This idea has been developed to the point that now a complete substation of 1,000 to 2,500 kva is enclosed in a common tank.

In considering the work done on fundamental transformer design, tests made with surge generators showed how to increase the impulse strength 50 per cent by a better arrangement of the insulating structures. Recently it has been found that this strength is increased a further 30 per cent by vacuum filling the transformer. This eliminates all the gases in the windings and, therefore, raises the point at which corona begins to form, which is the starting signal in the failure of an insulating structure in this type of equipment.

At the same time it has been found that if the oxygen is eliminated from the transformer, greater short-time loads can be carried with the same margin of safety than can be carried by the same transformer operated open to the atmosphere. As a result of these findings, transformers are now being vacuum filled and fitted with equipment to exclude oxygen, or are being sealed so that no air can enter, therefore operating as oxygen-free transformers. The former principle is used in large high-voltage transformers while the latter is used in the transformers of 1,000 kva and less. The development of a relay to permit the loading of transformers by copper temperature allows taking full advantage of these findings.

In all this work we find a decided trend to the impulse testing of transformers. In the case of the *CSP* (completely self-protected) distribution transformer where the protection is incorporated in the design, the completed transformer now gets a final impulse test with a current discharge of 65,000 amperes. The Westinghouse company has impulse-tested approximately 150,000 distribution transformers with approximately 800,000 kva rating and 175 power transformers with approximately 2,100,000 kva rating.

## DISTRIBUTION

One of the outstanding trends in the field of distribution has been the increasing use of static capacitors for power factor correction. The hanger-type unit can now be installed for eight or nine dollars per kilovolt-ampere. As a result of this low installed cost, the use of capacitors has grown fast in the last two years. They are now being justified on the basis of releasing system capacity, resulting in an over-all saving in total system investment. This is particularly true on the systems operating with low power factors. When it is realized that 1.3 kva corrective on 65-per cent-power-factor circuit and 2 kva corrective on a 90-per cent-power-factor circuit will release 1 kw of system capacity, it can readily be seen that this investment of $13 to $20 per kilowatt of released capacity may be readily justified depending on how far back into the system the capacity is released. Improved voltage conditions on primary feeders also may dictate the amount of corrective capacity that can be justified.

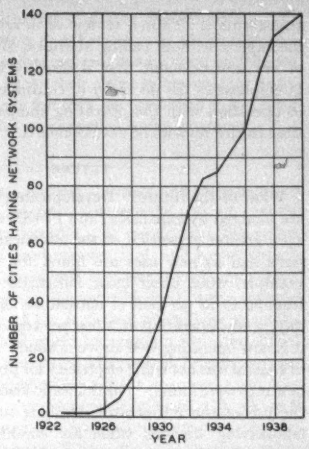


**Figure 7. The trend in the use of the a-c secondary-network system**

The use of the low-voltage a-c secondary network system continues for concentrated load areas, or where reliable service is required. Figure 7 shows the growth of this scheme. It has even been used in the supply system for station auxiliaries in one station and is receiving consideration in a number of others. Its use no doubt will expand.

The desire to eliminate oil in vaults located in buildings or congested areas has led to the use of a noninflammable liquid in place of oil. The Westinghouse company has built over 1,000 of these transformers to date. Precautions must be taken to provide for venting of gases given off if a fault occurs in them, as these gases are noxious. A dry-type transformer has now been designed and a number built for this class of distribution system or for use in industrial or central-station plants where oil is a hazard.

## RESEARCH

So much for the apparatus itself. It is of interest to see how many of these developments are dependent on or originated from research ideas. In some manner practically every one can be traced back to some research investigation. Improvement in generating units required extensive research to secure metals that would withstand the high temperatures and stresses met in the larger machines. Research gave us the instruments to conduct our field investigations on lightning which have been so far reaching. Research gave us the ideas on how to produce a dry-type breaker. It gave us the conception of eliminating oxygen from transformers to improve their rating and impulse characteristics. It gave us noninflammable liquids for transformers and insulation for the dry-type

transformers. Thus a review of developments would be incomplete without calling attention to the necessary part of our advancement that is directly traced to research. It emphasizes the necessity of continued research in close co-operation with the operating companies to make possible future reviews of developments.

### FUTURE

What of the future? Developments and improvements are fostered by expansion, and I believe that we shall find even greater expansion of the electrical industry than we have had as new uses are found for this servant. For example, when other basic industries were operating at from 30 to 70 per cent of normal we find the electrical industry was operating at a few per cent below normal, and it is now operating well above normal. Although industry in general was not using electricity for production purposes, new uses were found. The domestic load increased through the use of the refrigerator, washing machine, and other laborsaving devices, while air conditioning materially improved the commercial load. This trend has been so marked that system peaks now come on hot Tuesdays in the summer when iron and air-conditioning loads are a maximum rather than during the usual Christmas rush. Also, instead of getting one day with an outstanding peak during the year, a large number of days will show loads very close to peak. Thus as business picks up (and the prospects look better than ever at present) new peaks will be made in the electrical industry. Even a pessimist must agree that there is a very definite future for this industry.

To meet this the electrical industry will produce better and more efficient apparatus. Although the largest 3,600-rpm machine to be built is the 81,250-kva unit now under construction, the designers would not hesitate to build a 100,000-kw unit at this speed. Water-wheel-driven generators are now limited only by manufacturing facilities, so that the industry is now ready to build any size within these limits.

Although there has been no demand for higher transmission voltages, the industry could produce 330-kv apparatus with present design knowledge. All high-voltage lines now being built will be of the lightningproof design and means will be found to make the low-voltage lines lightningproof at a reasonable cost. The quick clearing of faults no doubt will be studied for improvement although with a decrease from 25 cycles to 8 cycles already accomplished with modern interrupting devices, the remainder will be gained at a slower rate.

On account of the improvement in the efficiency of smaller generating units, the trend no doubt will be to placing smaller steam stations close to load centers, thus minimizing transmission costs and losses at the expense of possibly a slight increase in operating charges. These stations will have dry-type breakers throughout and oilless indoor transformers for the auxiliary supply.

In the distribution field the demand for better service will be met with new and improved methods. We find a larger number of companies using the low-voltage a-c network for the heavier load densities and a number trying different schemes for the lighter-density areas.

More and more complete equipment will be factory built, assembled, and tested, making the installation time and expense a negligible part of the cost. In other words, there will be a greater tendency to have equipment thoroughly tested at every point in the manufacturing process so as to insure a well-balanced finished product.

It is only by diligence of thought and the spending of money for investigations and research that we progress, and sometimes the path seems a difficult one. In a talk at the dedication of the American Rolling Mill Company's research laboratory, Doctor C. F. Kettering emphasized this point by an interesting illustration. He admitted that many discoveries were stumbled onto quite by accident but pointed out that there was a reason for the accident. For instance, he said that if we should shut out the light from a room and place a chair out in the center no one would know where it was; but if some venturesome soul began to walk around in the room he would find the chair; he might stumble over it and skin his shin, but at least he would find it. We can be sure that nobody would find it if everyone sat still and did nothing.

It is apparent from past diligence in all phases of the electrical industry that we are determined to be up and about, groping around, possibly, and to some extent in the dark, but we are not holding back for fear of skinning our shins; we will be quite happy if we don't break a leg.

## History of the Electrical Industry

"THERE is no written history of the electrical industry . . . There is under preparation a history of the electric-utility industry, but that naturally can cover but a part of the complete story of electricity. What has been the course of electrical engineering, of design, of generation, of utilization, of construction? We have had a history of lighting, but what of transformers, of motors, or protection, or all the host of things that go to make up our equipment side?

"Why have a history? The answer, it seems to us, should be obvious. Only a few men are living today who saw the beginnings of commercial electricity. Each year brings new talent to us. These new men need to know what has happened in the past as a guide to their future activities.

"Fortunately, whoever undertakes to compile such a history will find a wealth of material quickly available. Since the beginning the industry has had its journals to record the progress of the art, and early it had its associations, the proceedings of which are primary. It also has several manufacturing companies that started in the pioneer years. And finally, there are some men who go back to the beginning, or nearly so, whose memories are storehouses of early developments. And unless we act quickly, many of these minds will be stilled forever and the loss will never be recoverable."

—*Quoted from an editorial in* Electrical World, *January 27, 1940.*

# Should Engineers Join a Union?

R. W. SORENSEN
FELLOW AIEE

**Pointing out that engineers should have the right to join unions or not as their own consciences dictate, this author believes that by doing so they are likely to impair their claims to professional status, and suggests that they are competent to find other ways of correcting unfair situations.**

ENGINEERS attain professional status in a unique way. Lawyers and physicians, upon the completion of the prescribed formal educational requirements of their respective professions, are immediately inducted into the profession by the opening of an office for practice or by joining forces with others of the profession in an established office. Engineers, upon the completion of formal educational programs (usually the work prescribed for a baccalaureate degree), get jobs as general roustabouts doing things which more often than not give no immediate evidence of a need for higher mathematics, modern physics, advanced engineering knowledge, or ability to apply engineering technique. Even at best, novitiate engineers cannot expect closer acquaintance with the real engineering problems they long to solve than that obtained by observing how engineers direct the things they are doing, or that which may be incident to training courses involving the simpler phases of manufacture and operation together with some class instruction. The latter is more often preparation for future engineering work than a study of the tasks performed in the daily training-course routine.

However humble the first jobs for graduates of engineering colleges may be, those performing the duties incident thereto soon demonstrate their qualifications or lack of qualifications for success in the practice of engineering as a profession. The reasons why this is so are clearly declared by the following statement of Gano Dunn,[1] "It is not what the engineer does, but how he does it! Not what the engineer's occupation is, but the intellectual processes by which he attacks that occupation." In other words, the engineers employed in industry do not occupy horizontal levels in the industrial scale of achievement and responsibility, but are found scattered throughout all its many departments.

Engineers in a number of occupations and localities have recently been subject to considerable pressure to unionize. This pressure has been very largely from outside organizations, rather than from the engineers themselves. Indeed such minor urge for unionization as has come from the engineers seems to be limited to those members of the great fraternity of engineering graduates who have never really become engineers, because of inability to keep up with the advancements and demands of the profession; or who have been so unfortunate as to obtain employment with firms having the shortsighted policy of getting from their technical staffs all the service possible by paying a minimum wage rather than a just compensation for the work done. This error is rare, because fortunately few industrial firms tolerate for long executives who by such practice show little knowledge of the type of management essential to continued business success. Indeed the movement to unionize engineers, set up a few months ago, at present seems to be at a very low ebb. In my opinion, this is due to the prevalence of good management, and a corresponding failure on the part of able engineers to see any reason for an engineers' union. Though the crest of the demand has subsided, aware of the fact that when there is smoke there is some fire, and urged by requests from the AIEE and the American Society of Mechanical Engineers committees on the economic status of the engineer, I am constrained to say to our younger engineers: "Look well before you leap—engineers who join unions may be committing the act which for all time classifies them as craftsmen and forever bars them from attaining the status of professional engineers."

Reasons why this is true should be quite clear to persons who analyze questions in an engineering way. James H. Herron, in a paper entitled "Unionization of Engineers"[2] says, among other things:

> "The most important union which has grown up in engineering types of employment is the Federation of Architects, Engineers, Chemists, and Technicians, affiliated with the CIO. The aims and viewpoints of this organization appear to be quite in accord with familiar labor-union purposes and ideals. According to a report of an annual meeting of the Federation which appeared in the *Architectural Forum* for November 1933, the Federation supported the following program:
>
> "1. Thirty hours of work per week.
>
> "2. Only 'extreme emergency' overtime, to be paid for at double-time rate."

Any code which prescribes such limitations is obviously designed to guard against exploitation of craftsmen and regardless of the success attained for that purpose is quite out of place for professional men doing mental rather than physical work. Such work cannot be handed on to others at shift-changing time or in many cases even be deferred until another day. Engineers, therefore, who develop habits of thinking in connection with their work as prescribed by the union code would be in grave danger of self-disqualification as professional men.

History proclaims the truth of the ancient saying: "For as a man thinketh, so is he." Men whose thoughts are directed to such objectives as a minimum of work for a maximum of pay cannot expect to experience the joy of finding an interest in their work which transcends all other interests. Without that supreme interest in a profession which makes men forget everything but the problems to be solved, and causes them to work to the limits of health and endurance forgetting time and even many of the social demands of their fellow men, there can be little probability of professional success. Professional success means that when men have finished their active years of engineering practice, they can take a backward look and say: "Those are our additions to the knowledge and the practice of our

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profession; because of what we have done men will live better than would be the case had those things been left undone."

Engineers are professional men aiming at high standards and striving to attain the same degree of recognition as that accorded the legal and medical professions. In case of severe illness, how much confidence would a patient have in a physician who after a few conferences said to him: "You will have to wait until next week for attention; I have worked all the hours I am allowed this week and can give your case no further thought at this time; or, if I do, I'll have to double my usual charge"? Perhaps the patient would need no further attention if very ill. How often would persons in need of legal aid and advice employ an attorney who said to his clients: "My allotted weekly number of work hours has been used. This is indeed unfortunate, because I have just thought of a line of argument which would be very favorable to your case if it could be studied and used for next Monday's trial, but nothing can be done about it; we must do what we can with the preparation that has been made"?

All professions include two types of work; namely, work of a research type which tends toward new developments that will enable the profession to keep pace with its rapidly and constantly changing problems; and work which can be done only by technical specialists, but is so repetitious that for the professional practitioner it becomes largely routine. The physician does his routine work in the daily treatment of his patients' minor ills; the lawyer in his preparation of the many simple agreements that are a part of the normal activities of his clients; and the engineer in his everyday tasks of building and operating standard apparatus and equipment.

No definite portion of a man's actual years in a profession which should be devoted to the training work of drafting, operating, etc., can be prescribed, but it is obvious that some stay at it overly long and become permanently subprofessional rather than professional engineers. If many have to do this simply because they are the forgotten men of the profession, such men, of course, will become discouraged and, if there seems no other way out, will think of unionization as a way to obtain coveted professional standing and increased pay.

The responsibility for this onerous situation may belong to unwise management; or to the failure of engineers to qualify properly for work more complex than their current occupations; or to a combination of unwise management and lack of forethought on the part of engineers in anticipating the requirements of the larger responsibilities that come with desired promotion.

Engineers must do their part by keeping well qualified for advancement, and management must do its part by avoiding tendencies to have advancement opportunities become departmental and by keeping working conditions and salaries for engineers at levels equitable in comparison with the work done and wages obtained by craftsmen by union methods. The question of wage is hardly pertinent to this article, but quite often one encounters, particularly in operating organizations, a deficiency in promotional programs that makes free transfer from department to department very difficult or even impossible. This situation seems to be more acute where promotion is obtained by examination (as in civil service) than it is where examinations are not used, although not all organizations using the latter scheme are free from this fault. In some instances, men have found it necessary to resign from a company and be reemployed for another department to get the consideration desired.

The question as to whether engineers shall or shall not become members of a union must be considered entirely as a personal matter for each individual, who as such has the free right to choose what seems to be the better way. This does not mean that the engineering societies have no responsibility in advising young engineers, who are the ones most affected by the decision regarding the question of unionization, but it does mean that the responsibility of these organizations should be only that of providing information and education concerning the influence of such decision, rather than making rules or prescribing whether members of the societies should or should not also be members of an engineers' union. In other words, freedom of action dictates that engineers should have the right to be union or nonunion men according to the dictates of their own consciences.

If the trend of thought in the near future indicates that engineers need more information for determining what the dictates of their consciences should be, does it not seem logical to expect that such information may be obtained effectively without the formation of any new engineering societies? Furthermore, should the results of a survey made to gather that information be such as to indicate that the engineers are not getting the recognition or compensation to which the services they render entitle them, does it not seem logical to expect that engineers are competent to find ways for having situations that seem to them unjust analyzed and corrected by peaceful methods rather than by such drastic methods as practiced by unions? One of the better methods is that used by the American Association of University Professors when a teacher reports that the college or university by which he is employed has been using unfair practice.

Indeed, engineers will delay the attainment of the high professional status so eagerly sought in direct proportion to the amount by which they deviate from the high ideals epitomized by Doctor Vannevar Bush,[3] president of the Carnegie Institution and formerly vice-president and dean of Massachusetts Institute of Technology, in his address before the meeting of the American Engineering Council in January 1939, as "the heights of true professional attainment, where honor and individual recognition by fellows is the real reward, and where the watchword is that old, old theme, which has never lost its power, and which may yet save a sorry world, simple ministration to the people."

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# "This Culture"

JOHN C. PARKER
FELLOW AIEE

**Deploring the "uneasy self-consciousness" that afflicts many engineers in considering "culture," Past President Parker suggests that the culture which consists of mental flexibility, sympathy with others' interests, and understanding of the relation of one's profession to society also may be instilled through great teaching of technical subjects.**

INCREASINGLY, members of the engineering profession have become concerned over the state of their souls, and in increasing degree have become conscious of cultural deficiencies in the profession. This concern over the social shortcomings of the engineer is not peculiar to the teachers of engineering but indeed is pretty active in the expressions, if not in the minds, of practicing engineers quite remote from educational activities. It may benefit us to do a little bit in the way of analyzing what, if anything, we have in mind.

It's frightfully hard to discuss the cultural state of the engineer since, like many another quality, it almost vanishes by virtue of being questioned. People sensitive to the high demands of personal honor are not likely willingly to discuss their integrity. One's affections are so sensitive a thing as almost to take flight through the assertion of their existence. Our nearest approach to safety in the present discussion may lie in the cowardly refuge of discussing the profession as a whole, except for those of us who are here present.

Concern for the intellectual and spiritual background of our profession may be worthy or it may be tawdry, depending altogether on the motives actuating that concern. I feel that, to a large degree, much of the discussion among active practitioners, and teachers as well, on this particular subject of culture is of a sort which cannot accomplish its ends until by use we have got so far from the original motivation that the source has completely been forgotten. I refer to the often-expressed belief that the engineer can increase his financial take or his status in society by a self-conscious or by an administered effort to expose him to things outside the narrow range of his profession. Such a motivation is mercenary or snobbish. It is the sort of thing that makes the very name of culture a repugnant thing. It is no different from a desire to be seen with the right people, to be correctly clothed according to the prescriptions of a haberdasher's schedule, or to be proficient in the precepts of Emily Post. A desire for culture as a means of gain or of either personal or professional acceptability merits and inevitably will receive the climber's reward.

To the degree that we concern ourselves with the ability of the young engineer to live a richer and fuller life, to the extent to which we address ourselves to improving the ability of our profession to serve the society—to that degree we must give fuller consideration to things beyond the limits of our technical fitness for our jobs. With such a motivation we won't speak of "culture."

Is this too nice a differentiation? I think not. It seems to me to be about the same thing as the distinction between politeness and courtesy. The latter is "of the court", a way of life, and will, when occasion warrants, violate all the formulae for surface polish though appropriating to itself such practices of politeness as are at once the means for and the evidence of a nice consideration for the rights and feelings of others. So, granted a fundamentally sound motive and reasonable sensitiveness, I think the evidences of culture cannot be lacking. With unworthy motives only the evidences can appear and they will crack through under stress.

This culture is not a superficial adornment to be applied from without but something that must have its origin in the very soul of a people. The outward expressions must flow from what is within if we are to avoid the artificial, even the ludicrous. The barbarian may have a fine dignity and an essential nobility of character. His dignity becomes pomposity and his nobility becomes a hideous toadyism when he attempts to appropriate to himself the external stigmata of civilization. We of the western world have done something of this sort as we have viewed European civilization. Instead of admiring frankly the fine things possessed by the older world while at the same time remaining keenly conscious of our peculiar contributions to the civilization, we have on many occasions erred in one direction or the other, in both cases giving evidence of an uneasy self-consciousness. Some have deprecated all things American and given an indecent adulation to European culture. Others have been assertive of our least noble attainments—mostly the possessive ones—and contemptuous of the things developed and prized in the centuries of European growth. Still others, and perhaps the majority, have done both things simultaneously.

I believe engineers quite commonly have pursued a parallel form of snobbery. We know the rugged engineer who assertively glories in the fact that he has a redblooded contempt for poetry. We know the deprecatory type who are willing to refer to themselves and to their fellows as mere blacksmiths.

Is it perhaps from this self-consciousness that much of the discussion of culture for the engineer arises? Is it for this reason that engineering curricula seem to say, "go to, now, we're going to get culture"? Is it something of

Verbatim transcription of an address delivered at the fall meeting of the Middle Atlantic section, Society for the Promotion of Engineering Education, Brooklyn, N. Y., December 9, 1939.

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this sort which leads to the inclusion in school catalogs of a statement which might be paraphrased somewhat after this fashion: "We give 'em a real practical education, but out of the four years we chisel 10 per cent in which we make 'em take culture, damn 'em."

And what of this grudgingly conceded 10, 15, or 20 per cent of meticulously computed "culture"? French and/or German and/or Spanish, "for engineers", half apologized for, because forsooth the engineer may want to read a foreign article in the original or to do business in Latin America; but nothing under any circumstances of the great literature or of the institutions of France or Germany or of the glory that was Spain (slightly to paraphrase). English—report writing for engineers, but heaven help the poor fool of a student who would like to know something of Chaucer or of the Elizabethans. Economics because it's the fashion of the day and because the engineer must carry on his job as an adjunct to economic process, but never—so help us—a study of the archaic Adam Smith or of John Stuart Mill as a preparation for citizenship. Even psychology because the youngster can be cajoled into believing that it will offer him a facility in outsmarting the other fellow.

If this be culture, lead me to the smithshop where my soul can glow with the iron under the hammer, where its resistive co-operation can communicate its qualities through fingertips and muscles to my inner being, where through frustration and persistence I can experience the joys of attainment, but where by no stretch of the imagination will I find a misleading label of culture, and yet the elements of culture are there.

Mere workmanship never can rise to the level of a fine art, but equally it may be doubted whether great art ever has existed except as it has been grounded in sincere and loving workmanship—in a workmanship so devoted that the artisan has poured all of his aspirations and of his ideals through his peculiar medium of expression into the thing that he has created. Isn't it this fine workmanship that identifies the work of the medieval armorer, the builder of a great structurally honest cathedral, a Rodin carving a vital "hand of God" and giving warm life to cold marble, and the musicianship of a Koussevitzky? Isn't it the high intellectual integrity and love of the work that gives an inspired craftsman the same gentleness and the same nobility whether he be a millwright, a guide on a fishing stream, a sonneteer, or a statesmen?

I am sure that you all know precisely what I mean—that in your personal acquaintance you number many finely cultured gentlemen, who, through their vocations, have developed sensitiveness and strength of character without benefit of either social or scholastic background.

### DANGER OF STERILITY IN ARTS COURSES

By no manner of means are all of the sins in the name of culture committed in our curricula of engineering. As I believe there is no cultural salvation merely in the "dieder-den-die" business of elementary German, so I would find cultural sterility in a Browning course made up of scholarly footnotes which may bury the throbbingly vital humanity of "The Ring and the Book" so deep in academic dust as to make Browning as obscure as he is sometimes believed to be.

Let us make sure that we differentiate scholarship from culture. Each complements the other; each is almost essential to the other; and yet they are different things. I would not for a moment deprecate sound scholarship in any field, nor would I be thought to condemn the mechanical preparation in the elements so necessary to a full attainment of the later joys. Simply I insist that courses in the liberal arts are neither liberal nor art if they fail to get beyond the mechanics of preparation or the minutiae of research. Too often this is precisely what does happen. The invasion of the scientific method into the humanities has done wonders for research but often at the expense of the liberalizing and human values in the subject matter. Too often the attractions of scholarship have resulted in slovenly and frightfully mechanical processes in the elemental preparatory courses, perhaps with the thought that scholarship is great and elemental teaching only a painful incident thereto.

If our courses in the liberal arts must be given in their initiatory phases without the joy of discovery by the student, and in their more advanced development primarily as exercises in scholasticism, I maintain that there is precious little of culture in them. Better by far would the student pursue research in the more exact mathematical and physical sciences and in their professional derivatives where the scientific method is most highly applicable; better by far would he spend his time in an intensified discovery of elemental things close to his vocational interest.

Sending our students across the campus to take courses in the rarefied atmosphere of the liberal arts is not enough. We must make sure of the treatment that will be given to the courses which they may elect and of the existence in their teachers of a nice combination of patient workmanship, fine scholarship, and high vision.

As I sense this business of culture, it's not a matter of hanging some academic trappings on the outside of a boor or of training his tongue trippingly to repeat phrases or to refer to events in history which have left him, as a man, quite unmoved. Rather it must be to develop mental flexibility, a sympathy with the viewpoint of people of divergent interest, and understanding of where one's own vocation fits into the interests of the society to which it is at the most only ancillary. If, as one reads his Chaucer, he journeys with the Canterbury pilgrims to the shrine of Thomas and on the way experiences the manysided current humanity through which, through the ages, one increasing purpose runs, he will come to understand that his engineering, his medicine, his law best serves its function in a very human world if prosecuted to meet the needs, the desires, the very human prejudices of an actual world. He will understand, being an engineer, that men are not interested in engineering accomplishment if brought through at the expense of human suffering and maladjustments, of hideousness, dirt, and noise, or as a harsh technique intruding itself into the gentler affairs of life.

"But," one may say, "this has little to do with the work

of the engineer. It may fit the doctor and the lawyer, the preacher, who deal with human beings and with human affairs. It does not touch the engineer. His work is objective and has to do with things—with structures, machines, and circuits." Is it so? I think not. Elsewhere I have tried to develop the thought that of all the professions our profession of engineering is the most social, the most human; that the engineer works not as an individual but collectively with others—researchers, designers, producers, and adapters—to direct the forces and materials of nature entirely for the service of mankind; that his profession, above all others, serves organized society and that therefore his work must be administered not only co-operatively with others but to the end of meeting the needs, the desires, the prejudices of human groups. If this be so, the engineer must, of all men, be mentally flexible, capable of adapting himself to men of different vocation with whom he must collaborate and of visualizing the social objectives of his work, its impact on the lives of others, its influence on their institutions and preferences.

The understanding of these things is not foreign to the nature of the youngsters who come to us for their schooling. They are human and as capable of mental flexibility, home background being the same, as are the young men entering the other professions. The job of the teachers of the humanities is to develop from latency into activity the mental and spiritual awareness of these students. This calls for great teaching but no greater than we ask in the technical courses. The difference is only in the media of education, and even as to these the difference is not so vast as it might seem.

### CULTURAL VALUES OF GREAT TECHNICAL TEACHING

Indeed sometimes I doubt whether we are fully aware of the values that we have at hand in our scientific and technological courses for accomplishing the very purposes for which we introduce cultural requirements into our curricula. I know that the indicated courses in mathematics and physics, in chemistry, and in geology are intended primarily to equip the students with implements for the accomplishment of technical ends. I know that beyond that many of us feel that there is disciplinary value in these subjects, that the powers of observation and of close logical reasoning are developed through these pre-engineering courses. Is that all? Isn't there, beyond these more or less utilitarian values, something infinitely fine if only we can inflame the imagination of our students? Isn't there a satisfaction of the sense of sheer physical beauty in the graceful sweep of a parabola; isn't there an appeal to the sense of order and rhythm in an algebraic series?

It was my good fortune as an undergraduate to take courses in structural analysis with a great teacher whom I recall as the inventor of the method of area moments for the graphical analysis of trusses and arches. The man loved his subject. Some of that affection communicated itself in his teaching. It is true it was a course in civil engineering. Equally truly, it was a course in which we learned something of a universe of law and order, in which we gained confidence that there were no closed mysteries that could not be solved by a modest but persistent mind. It meant something to us that the great arches which some day will support the central tower of the Cathedral of Saint John the Divine have their very being in a different but equal beauty in the method of area moments. A course in geology given to us as vocational foundation was so divinely inspired that the mountains, the hills, and the streams will always add beauty to the landscape because they are full of meaning in a structural sense.

These men had no thought of departmentalizing culture. I doubt much whether they were ever quite conscious of it as an adjunct to engineering education. This I know—because they had wide intellectual horizons, because they had great love for their subjects, because they were aware of the gorgeous intangibles in the things they taught, they communicated some faint bit of their wideness of vision to us young unregenerates. No man could take a magnificently interpretative course in the theory of dynamics of the rigid body with a professor who was a distinguished linguist, a skilled amateur of the violin, an historian and an economist, and with all a very fancy figure skater, and at the same time have either contempt for the niceties of mind and soul in other men or deprecation of the elements of those qualities in his own profession.

Teachers such as these work greatly on the young men who sit under them. Both in themselves and in their approach to the technical subject matter of their courses they carry the cultural essentials. They have a reverence for learning for its own sake and a respect for it no whit abated by the fact that it may be put to work. They speak the King's English with appreciation of it not only as a wonderful medium for the communication of ideas but as a source of enjoyment in and of itself. Their hours of leisure may find them occasionally listening to good chamber music, reading modern or classical writings not for the subject matter alone but for sheer enjoyment of the writer, participating in the affairs of men because they know that people are greater than their creations. Such teachers ungrudgingly see their students, in the spirit of true amateurism, making excursions into unvocational fields. Equally they resent any implication that their own work can be less than scholarly, least of all narrowly vocational.

Without such teaching in the technical courses all the cultural courses in the curriculum are without effect. Lacking this everyday domestic point of view, they are as pointless as Sunday piety among the irreligious or as the sending of a youngster from a vulgar home into an importuned contact with a narrowly modish group.

What I have been trying to say comes down pretty closely to this: that the finer culture of the minds and souls of our young engineers will lie in the fitting of them to enjoy their jobs and their lives outside their hours of work and in helping them to learn sympathetically to view the interests and the vocations of other men; that this can be done through helping them to find the less obvious qualities in various matters coming within the range of human interests; and that this culture is to be had only through great teaching, whether it be in our professional courses or across the yard.

# Room Noise at Telephone Locations—II

D. F. SEACORD
ASSOCIATE AIEE

***Surveys of room noise at various locations under both summer and winter conditions provide data for annual averages and distributions of room noise, and indicate the relative importance of major noise sources***

AS PART of a study of room noise and its effects on telephone transmission, a broad survey of room-noise conditions at telephone locations has been made by Bell System engineers which has provided information relating to the magnitude of room noise at various types of locations and its variation from place to place and from time to time.

Room-noise data, based primarily on measurements made at about 900 locations in and around Philadelphia and Chicago under winter conditions, were reported informally to the conference on sound at the 1939 AIEE winter convention (see footnote). The present article supplements the earlier material and includes a summary of room-noise conditions expressed in terms of annual averages based on both the winter survey data previously discussed and the summer survey data that had been obtained at about 1,300 locations but had not been completely analyzed at the time of the earlier report. The summer survey included 500 measurements at locations previously measured during the winter in and around Philadelphia and Chicago, and 800 measurements at locations in and around Cleveland, New York City, northern New Jersey, and Philadelphia. Annual average as used in this article is the mean of winter and summer measurements. In addition, the present article includes a brief discussion of outdoor noise and the relative frequency of occurrence of several predominant sources of room noise.

The noise measurements were made with equipment conforming to the specifications described in the ASA "Tentative Standards for Sound Level Meters" (Z24.3-1936), using the 40-decibel loudness-weighting network. The measurements are expressed in terms of sound level in decibels above reference sound level, that is, $10^{-16}$ watt per square centimeter at 1,000 cycles in a free progressive wave, each measurement being based on the average of 50 individual readings.

Since room noise is a highly variable quantity it is desirable to express the results of room-noise measurements in such a way that both the average value and the degree of variation involved are described. For a particular type of location, for example, the average value is obtained from the total of the measurements at all locations of this type. The degree of variation involved is expressed in terms of the standard deviation, this term being a measure of the spread of the measurements. The results may also be expressed graphically by means of distribution curves showing the cumulative per cent of locations having noise values of a given amount or less. The distribution curves included in this paper have been prepared using an arithmetic probability scale, so that cumulative normal distributions appear as straight lines.

In order to give a condensed summary of the room-noise data obtained at various types of telephone locations, generalized distribution curves covering room noise on an annual average basis are shown on figure 1 for the three broad classifications: residence, business, and factory. The data for residence locations are shown in two parts, covering conditions with and without radios in operation, respectively. It will be noted that the measurements in residences where radios contributed to the general noise level indicated room-noise values approximately halfway be-

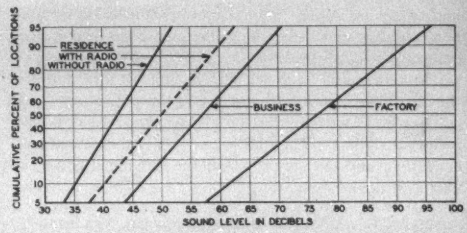


**Figure 1. Distributions of room noise based on annual average levels**

## Summary of Annual Average Values of Room Noise and Differences Between Summer and Winter Conditions

| Type of Location | Annual Average Values of Room Noise (Decibels) | | Summer Versus Winter (Decibels) |
|---|---|---|---|
| | Average | Standard Deviation | |
| Residence | | | |
| without radio | 43 | 5.5 | 3 |
| with radio | 50 | 8.0 | 4 |
| Small store (< 6 clerks) | 53.5 | 7.5 | 4 |
| Large store (> 5 clerks) | 61 | 6.0 | 0 |
| Small office (< 3 desks) | 53.5 | 6.5 | 4.5 |
| Medium office (3 to 10 desks) | 58 | 6.5 | 1 |
| Large office (> 10 desks) | 64.5 | 4.5 | 0 |
| Factory office | 61.5 | 9.5 | −2 |
| Miscellaneous business | 56 | 7.5 | 1.5 |
| Factory | 77 | 12.0 | −2 |

Based upon a report made at the conference on sound at the AIEE winter convention, January 22–26, 1940. An earlier report on the same survey was presented at the 1939 winter convention and published in the June 1939 issue of ELECTRICAL ENGINEERING, pages 255–7.

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tween those obtained at residences without radios in operation and those obtained at business locations. Also, the average room noise at factory locations is about 20 decibels greater than at business locations. These distribution curves illustrate the fact that room noise is a highly variable quantity and cannot be described adequately in terms of average values alone.

The data shown on figure 1 are also summarized in the accompanying table in terms of annual averages and standard deviations, giving the data for business locations in somewhat greater detail to show the noise conditions at various types of such locations. In addition, the table shows the average difference between summer and winter room noise at the various types of locations, based on comparisons made at about 500 locations under both summer and winter conditions.

Considering first the average difference between summer and winter levels of room noise, it will be noted that the largest differences occur in the case of residences and small stores and offices. This appears reasonable since it would be expected that the increment of noise from outdoor sources entering through open windows or doors under warm weather conditions would have a greater effect in these types of locations than in the larger establishments where the noise due to indoor sources (people and store or office appliances) is of greater importance. In the case of factories and factory offices the decrease of 2 decibels under summer as compared to winter conditions is due presumably to differences in the rate of manufacturing activity in the two seasons.

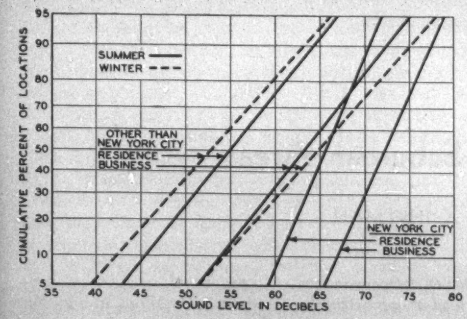


**Figure 2. Distributions of outdoor noise under summer and winter conditions**

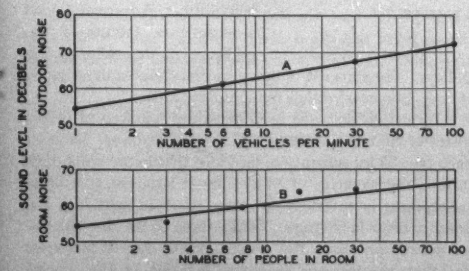


**Figure 3. Relations between (A) outdoor noise and vehicular traffic, and (B) room noise at business locations and number of people in room**

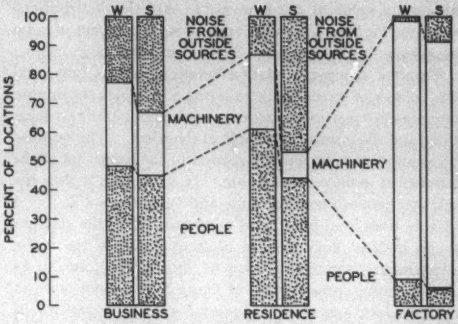


**Figure 4. Distribution of locations by predominant sources of noise**

The average levels shown in the table are based on measurements made in a wide variety of types of areas ranging from quiet rural regions to noisy city districts. The standard deviations shown thus include the effects of variations in the levels of room noise that occur from one type of area to another, as well as the variation between locations in a single area. In terms of annual average values, the room-noise data cover a range from about 43 decibels for residential locations without radios in operation to 77 decibels for factories, with the various types of business locations covering an intermediate range from 53.5 to 64.5 decibels. The standard deviations involved are of the order of 5.5 decibels for residential locations, 4.5 to 9.5 decibels for business locations, and 12 decibels for factories.

Since in many instances outdoor noise is an important contributor to room noise, measurements were made of outdoor noise at the street curb in front of the premises in which room-noise measurements had been made. The results of these measurements are shown by the three sets of distributions in figure 2, which are based on data obtained (1) under summer conditions in New York City, (2) under summer conditions in locations other than New York City, and (3) under winter conditions in locations other than New York City. Each set includes separate distributions for business and for residence locations.

Figure 2 shows that the average outdoor noise (for both business and residence locations) in New York City is of the order of 10 decibels greater than in the other areas. Also, the spread of the noise conditions in New York City is somewhat smaller, in view of the more uniform type of area, than that for conditions in the other groups of locations, which include a range from congested city districts to rural areas. Since measurements in congested districts in Chicago and Philadelphia gave values of the same magnitude as those obtained in New York, and since the distributions shown in figure 2 tend to approach a common

maximum value, it seems probable that the distributions obtained for New York City are also representative of noise conditions in the congested districts of other large cities.

Figure 3 shows the relation between outdoor noise and the volume of street traffic in terms of vehicles per minute and also the relation between room noise at business locations and the number of people in the room. The outdoor noise appears to be directly related to the logarithm of the number of vehicles per minute. It is of interest that the relation between outdoor noise and vehicular traffic found at this time is in very good agreement with the relation found in New York City in 1930, as shown in the Noise Abatement Commission's report on "City Noise." As shown in the lower portion of figure 3, the room noise at business locations tends to increase with the logarithm of the number of people in the room. In this case the results are somewhat more erratic and the slope of the logarithmic curve is somewhat less than that of the curve for the relation of outdoor noise to vehicle traffic. These differences are of the type which would be expected from a consideration of the sources of outdoor noise and room noise. Outdoors, vehicular traffic constitutes, in general, the major noise source; indoors, noise from outside sources and from machinery, which together form a substantial part of room noise, tend to reduce the effect of variations caused by people. Also, rooms containing larger numbers of people are usually larger in size, which tends to offset the increment of noise caused by the additional people.

In the measurement of room noise at each location, the source of noise judged to be predominant was noted on the data sheets. It should be appreciated that the level of room noise at a particular location is varying continuously. At each location measured each of the 50 individual readings of the sound-level meter was classified by the observer on a judgment basis as to the probable source that affected the reading. The location was then classified as to source of noise in accordance with the majority of the individual reading classifications. The results of an analysis of this information are shown on figure 4, with the sources grouped into three general classes: people, machinery, outdoor sources. Data are shown for winter and summer conditions separately for each of three general classifications of locations, business, residence, and factory. The winter and summer data are based on the results of the complete winter and summer surveys, respectively. Accordingly, although in each case the results are believed to be reasonably representative, the relations between summer and winter should not be considered quantitatively, since the locations involved are not identical for the two cases. It is interesting to note the relatively large proportion of both business and residential locations at which the predominant source of noise is people talking or moving about. It may also be noted that there is a marked decrease from summer to winter in the proportion of both business and residence locations at which noise from outdoor sources predominates.

# Power Supply for Suburban Areas

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**The practices of a large operating company in providing power supply for a load of approximately 150,000 kva in a 1,400-square-mile suburban area are discussed in this article, with the underlying causes—practical, economic, and electrical—for these practices.**

SOME years ago the load density of the strictly suburban area of the Philadelphia Electric Company was such that a fairly large percentage of the load was adequately supplied from 13-kv lines, but growth of load has made it economically desirable gradually to reinsulate a large proportion of these for 33-kv operation. By such change-over capacity was provided at lower costs than by any other means. Aside from reinsulating existing lines for higher-voltage operation, capacity has been provided by increasing the number of supply lines and by erecting 66—33-kv stepdown substations at new locations. In suburban areas, it is expected that load growth for many years will be provided for largely by the erection of new 66-kv stepdown substations in addition to the five now in use. Scarcity of low-cost routes for 33-kv circuits, service reliability, and increased load densities are factors of importance in determining this policy. Previous use of 66-kv in Philadelphia determined its selection as a voltage for suburban areas.

A principle that has been generally followed in recent years is that of installing but one transformer bank at each 66—33 kv substation, provided that in the event of its failure, the capacity of 33-kv lines to adjacent 66—33-kv substations is sufficient to carry the load with not too great a drop in voltage. While three of the five 66—33-kv substations have two banks, this is due to historical or other reasons, and is not a negation of the general principle.

In considering the problem of reliability of supply lines, it is helpful, as a guide for the intelligent expenditure of

Essential substance of AIEE paper 39-172, presented at the Middle Eastern District meeting, Scranton, Pa., October 11-13, 1939.

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money, to know approximately the causes for interruptions. Table I presents some data on causes of supply-line tripping in the suburban area.

It can readily be seen that if increased supply-line reliability is desired, the greatest emphasis should be on the elimination of outages caused by lightning, as such interruptions represent on the order of three-quarters of the total. Attention has been concentrated on this problem for some years in the past, with the result that lightning troubles on newly designed lines are approximately half of those previously experienced.

On all new 33-kv supply lines, as well as when complete rebuilding is undertaken, the aim is to secure a minimum spacing of two inches per kilovolt between conductors and between conductors and ground, as measured by way of the insulators, wood crossarms, and wood pole, except that on the insulators the arc-over distance rather than the distance measured over the surface corrugations is used in the measurement. In practice, at least 2.5 inches is usually secured. Experience indicates that substantial improvement is secured up to this spacing, but that little improvement results when it is exceeded. Aside from rebuilding lines to secure a minimum of two inches per kilovolt, a great deal of other work, such as lowering guys, has been done to increase spacing. Although such work does not always bring spacing up to the desired minimum, it does cause marked improvement in reliability.

In considering the need for expenditures to improve supply lines, it is desirable to know what proportion of the outages to the electricity supply system are due to supply-line troubles. Collection of such data may be laborious and costly, but the results should be of value as a guide for the expenditure of money. Table II presents some statistical data on the distribution of such outages in the Philadelphia Electric Company suburban area.

The need for stressing improved supply-line performance particularly for single-line substations, can readily be seen from this tabulation. Many lines serve both single and multiline substations. Customers supplied from single-line substations experienced about three times the outage minutes of those supplied from multiline substations.

## SUBSTATIONS

General practice for extremely light load-density areas calls for the use of single-bank single-line substations, largely because two-bank two-line substations would not be economically feasible. For such areas there is used either a pole-mounted substation (figure 1), or a recently developed factory-assembled self-contained 1,000-kva unit substation, shown in figure 2, which requires the minimum of work in installation and connection to supply lines and distribution circuits. The major advantages of the factory-assembled unit lie in its better appearance, and in the fact that very little investment has to be written off if it becomes necessary or desirable to move it to another location. Such unit substations on the Philadelphia Electric Company system are equipped with an air circuit breaker and tap-changing-under-load equipment with a 15 per cent range in eight steps on the low-voltage side, and suitable relays and load-recording equipment. Either external fuses or fusible links under the oil are provided on the high-voltage side.

For heavier load densities, multibank multiline substations are usually provided. On the Philadelphia Electric Company system, the most common type is the so-called loop substation which contains two transformer banks, each with a low-voltage automatic breaker and served on the high-voltage side by two 33-kv lines looped through a 33-kv breaker as indicated in the simplified single-line diagram of figure 3 and illustrated in figure 4. In case of fault on one of the 33-kv lines, the 33-kv breaker and the low-voltage breaker on the bank nearest the fault open automatically. The auxiliary bus is provided so that even with failure of substation equipment on an individual circuit, the load of the circuit can be carried without recourse to street breakdowns, although hand switching is necessary to put the equipment on the auxiliary bus. In one recent case of modernization of a substation, the auxiliary bus has been omitted. In its place, an emergency circuit supplied directly from one of the two transformer banks has been extended to the point on each circuit where the underground cable terminates and the aerial wire portion begins. By closure of a disconnecting device at this point, any circuit can be carried in an emergency. A still larger substation, shown in figure 5, is used where near-urban load densities are encountered. Table III gives the average number of interruptions per year, based on a five-year record, of substations of various sizes, and illustrates the increased reliability provided for the heavier loads.

The interruptions to the smallest substations are about nine times as frequent as those for the largest substations.

As indicated in table II, the reliability of the single-

**Table I. Causes of Interruptions to Suburban 33-Kv Supply Lines of Philadelphia Electric Company**

| Cause | Per Cent of Total |
|---|---|
| Line insulator flashover—lightning | 55 |
| Pole switch flashover—lightning | 8 |
| Wires down due to lightning | 13 |
| Wires down not due to lightning | 5 |
| Trees and foreign objects | 8 |
| All other causes | 11 |
| Total | 100 |

**Table II. Durations of 115/230 Volt Suburban Customer Outages, Expressed in Per Cent**

| Cause of Outage | Single-Line Substations | Multiline Substations |
|---|---|---|
| Source | 4 | 4 |
| Supply line | 50 | 5 |
| Substation | 12 | 1 |
| Distribution primaries | 28 | 78 |
| Distribution transformers | 2 | 5 |
| Miscellaneous | 4 | 7 |
| Totals | 100 | 100 |

**Table III. Average Number of Total Interruptions to Suburban Substations Per Year**

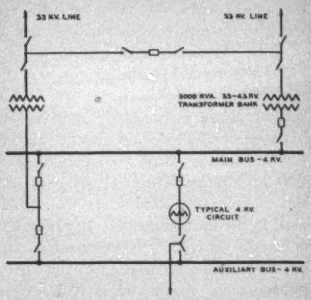
(Average of Last Five Years)

| Kva Load Per Substation | Number of Interruptions Per Substation | Number of Substations |
|---|---|---|
| 5,000 or over | 1.1 | 8 |
| 3,000 to 4,999 | 1.3 | 7 |
| 1,000 to 2,999 | 2.7 | 11 |
| 500 to 999 | 7.7 | 13 |
| 100 to 499 | 9.6 | 25 |

Figure 1 (left). Small pole-mounted substation

Figure 2 (left). Factory assembled, self-contained 1,000-kva unit substation

Figure 3 (below). Simplified single-line diagram of a 33-kv suburban loop substation




bank suburban substation service is as dependent on the reliability of its supply lines as on any other combination of factors. Approximately 50 per cent of the outage minutes in single-line substations and 5 per cent in multi-line substations are due to supply-line outages.

The major source of trouble within the substation itself is in the failure of oil circuit breakers. The fire which frequently follows breaker failure is particularly serious because of the headway it gains before it is known, as most suburban substations are unattended. The damage from the fire delays materially the return of the substation to service. Use of oilless breakers may prove to be the solution to this problem; various types of these breakers have been in active operation for several years.

Introduction of additional 66—33-kv substations will automatically provide for a radical improvement in the reliability of substation service by cutting the length of line exposure. On single-bank single-line substations, supply-line reliability should improve approximately inversely to line length. With lines of similar characteristics and equal chances of having interruptions on a per-mile basis, the relative probability of simultaneous outage to a two-line substation with its existing and proposed shortened lines, is proportional to the product of the length of the lines that supply it. Hence, if each of the two lines to a particular substation is cut in half, the probability of outage due to line trouble is cut to one-fourth. Such improvement is another factor which should be given considerable weight in determining whether capacity is to be provided by extending medium-voltage supply lines, or by additional high-voltage lines with their associated 66—33-kv substations.

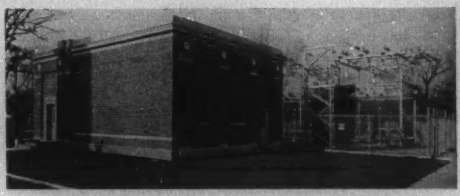


Figure 4. Typical suburban 33-kv substation with building developed for one-half its ultimate capacity

### PRIMARY DISTRIBUTION

The nominal distribution voltage most frequently used throughout the United States today ranges from 4,000 to 4,800 volts three phase. The adoption of such a more or less standardized voltage probably is due in part to the fact that the voltages that preceded it were either 2,300 volts three phase delta or 2,300 volts two phase. Change-over from either of these two systems was relatively easy because the phase-to-neutral voltage at 4 kv, for example, is the same as the phase-to-phase voltage on the 2,300-volt three-phase delta system and the phase-to-neutral voltage on the two-phase system. In any event these factors accounted for the use of a nominal 4-kv system in the suburban area around Philadelphia. For the lightest load-density areas, a higher voltage than 4 kv might locally show greater economies, but considering over-all long-time requirements, standardization at 4 kv is believed to represent the best solution.

One of the difficulties in the adoption of a 4-kv three-phase system over a 2.4-kv two-phase system lies in designing a satisfactory three-phase four-wire secondary system for combined light and power loads. With the two-phase system a five-wire four-phase secondary was used which provided 115 volts for lamps and 230 volts for motors. With three-phase, four-wire, wye secondaries, the three-phase motor voltage would be about 190 volts on a 110-volt system instead of 220, the standard motor

rating, which may make it necessary to use larger motors or autotransformers for motor supply. Proper solution of this problem lies in the design of a 190-volt motor for use on such combined light and power secondaries. This matter is being seriously considered by the industry at the present time and there appears to be no serious obstacle to the adoption of such a standard motor.

The problem of securing the maximum results from automatic voltage-regulating equipment on primary distribution circuits is greatly accentuated in suburban areas because of the greater length of the circuits. Among the distribution circuits from a particular substation, the probabilities are that there are some which will be heavily loaded when the substation load is at its maximum and on which the nearest customer will be at a considerable distance from the substation, and at least one which either will be very lightly loaded or will have customers immediately adjacent to the substation. The voltage drop on the longest circuit frequently makes it desirable to have the bus voltage at as high a value as possible so long as the regulators on the lightly loaded circuits or on circuits with near-by customers have sufficient bucking range not to give these customers too high voltage. Only by such a procedure is it possible to make use of the entire 20 per cent range of the plus-or-minus 10 per cent regulators commonly used. Failure to operate the system in such a manner may easily force the introduction of new circuits before the existing circuits are fully loaded, the use of costly auxiliary regulating devices out on the street itself, or the use of larger copper conductors in the street to reduce voltage drop.

In extreme emergencies, it is the practice of the Philadelphia Electric Company to permit the customer's voltage to sag below normal limits. Actually, there are three choices available for handling such emergency conditions: selected loads may be dropped, giving no voltage to some customers; voltage may be allowed to sag; or large sums of money may be spent in an attempt to give normal voltage to all customers. Because of the infrequency of occurrence, it is to the best interest of customers to permit the voltage to sag. The minimum permissible emergency voltage designed for at the customer's meter is 95, because tests on a group of new refrigerator motors indicated that all makes of motors tested will start when 95 volts is supplied but that certain motors will not start at 90 volts. At the present time, delivery of emergency voltages for 220-volt polyphase motors has not been much of a problem because combined light and power secondaries have been used to only a limited extent, but if their use becomes desirable on a large scale because of a new type of load, such as a residential five-horsepower air-conditioning motor load, inability to start such motors at 165 volts, which corresponds approximately to 95 volts single phase, may force the use of higher emergency voltages and result in a substantial increase in system investment.

An auxiliary advantage in operating with a high bus voltage, even though it normally may not be required for all or any of the circuits in the substation and even though it is so high that circuits never normally operate in any but the bucking range of the regulator, lies in the fact that it is possible to give customers more nearly normal voltages in emergencies than would otherwise be the case, or even to postpone the installation of an additional supply line. In suburban areas with long supply lines, voltage drop in the line, both normally and in emergencies, frequently requires the installation of additional lines, even though there is ample thermal capacity in the available equipment. Loss of one of the supply lines which serve a multiline substation accentuates the voltage difficulties and the voltage level at the substation bus may be reduced by substantial percentages. Regulation of bus voltage at 66—33-kv substations, by providing the highest voltage at the heaviest load period, can be helpful in substantially increasing the capacity of supply lines. This practice is used where voltage-regulating devices are available, subject to the limitations of near-by loads. In urban areas, normal and emergency bus volt-

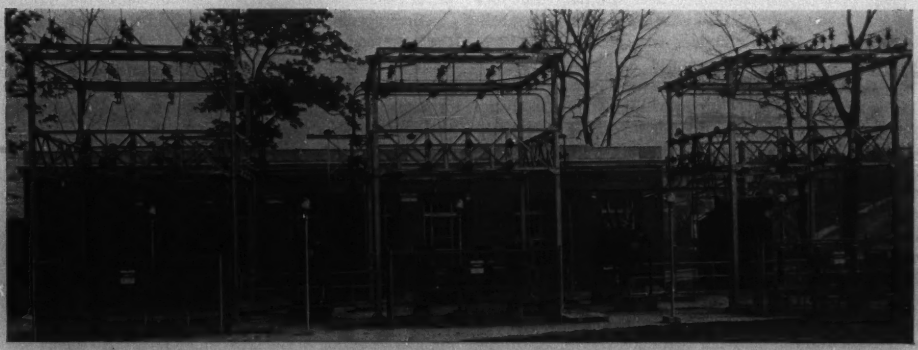


**Figure 5. Type of substation used for near-urban load densities**

ages are not generally a problem because cable supply lines are usually necessary, and aerial lines, if any, are short.

In recent years, increased attention has been given to the possibilities of distribution primary networks. Such networks greatly reduce the probability of outage to customers served from substations supplied by single lines, mainly because service is not interrupted when one line is lost. Of course, some improvement is also secured by reduction in outages due to primary distribution system troubles. Better normal and emergency voltage regulation and reduced voltage flicker are incidental advantages. Few of the single-phase branches and only certain of the main polyphase portions are actually tied together to form the network loops, and these probably represent substantially less than 50 per cent of the total circuit mileage. Complete network distribution at present load densities would involve costs out of line with the added gain.

# New High-Voltage Laboratory of the Bureau of Standards

F. B. SILSBEE
MEMBER AIEE

**More effective service to the Federal Government and the electrical industry, and broader co-operation with national technical societies are anticipated as the National Bureau of Standards takes over its new specially designed laboratory for high-voltage and X-ray work.**

ON APRIL 6, 1940, there was turned over to the National Bureau of Standards by the contractor the new $350,000 laboratory building that is to be devoted to high-voltage and X-ray work. This event marks a definite step in the growth of the Bureau and in its possibilities of service to the public and to industry. The work to be carried on in the new laboratory will be an extension of that done on a necessarily more limited scale in the cramped quarters hitherto available.

The work of the laboratory falls naturally into four classes: X-ray and nuclear physics studies, the precise calibration of voltage transformers, testing of insulating materials for the Federal Government, and research and development on methods of measurement at high voltages.

The new laboratory is an unusual building in many respects. It was designed by the office of the supervising architect, Public Buildings Administration, Federal Works Agency. Because of the special requirements to be met, the closest co-operation was essential between the architects and the laboratory workers. The bulk of the building consists of a single huge room 136 feet long, 65 feet wide, and 60 feet high, in which the equipment for the higher voltages will be housed. In front of this is a series of smaller laboratories, occupying five stories, in which apparatus for somewhat lower voltage will be installed and which will also contain office space and control apparatus for the higher-voltage equipments. The walls of the large room are lined with a layer of sheet copper and the exterior walls are thermally insulated with a three-inch layer of cork. The ceiling is metal, and steel armor has been cast in the concrete floor and bonded to the steel frame of the building. The metallic conducting lining serves three purposes. It makes the bound charges induced on the walls by the presence of electrically charged conductors definite and repeatable. It prevents interference with radio measurements in other laboratories, and it also makes the walls relatively tight against infiltration of water vapor. The climate of Washington in summer is so humid that many types of electrical measurements become impossible by reason of the leakage of electricity over the surface of insulating parts. Special equipment is provided in the new laboratory so that the air in the interior of the building can be dried.

Three openings are provided high in the north wall of the large room. The central opening is 16 feet square and the side openings are 10 feet square. The openings are normally closed but will permit a three-phase 600,000-volt or a single-phase 1,000,000-volt circuit to be run outside the laboratory for experimental purposes.

To protect the workers in the small laboratories at the front of the building from scattered X radiation, a heavy (12-inch) concrete wall separates them from the main room. Also, the targets of the high-voltage X-ray tubes are located within a 12-inch concrete "pill box" on the main floor. Lead-covered doors and concrete labyrinth passages separate the X-ray laboratories from the other half of the building.

In order to isolate all equipment which might produce noise or vibration in the main building, a small annex has been built, north of the main laboratory. This will house storage batteries, transformers, motor-generator sets, and compressors. Three experimental generators having ratings of 5 kva, 50 kva, and 1,500 kva, respectively, are provided. Each of these can be driven by a 60-cycle synchronous motor but alternatively can be driven by a d-c shunt motor when frequencies other than 60 cycles per second are needed.

The equipment for X-ray work includes a cascaded bank

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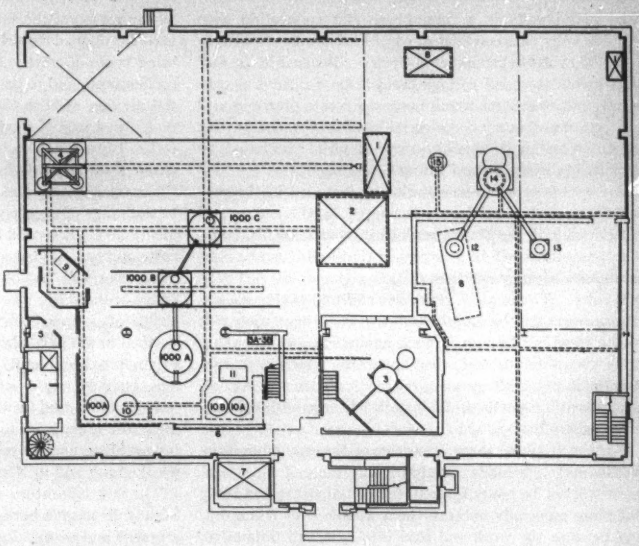
**Plan of main floor of laboratory**

1. Air ducts
2. Pit for oil tank
3. Brooks electrometer
3A-3B. Standard transformers, 25 kv
4. Impulse generator, 2,000 kv
5. Dark room
6. Distribution switchboard
7. Elevator
8. Hatchways to basement
9. Cathode-ray oscillograph
10. Air capacitor
10A-10B. Standard transformers, 100 kv
11. Shielded resistor, 500,000 ohms, 30 kv
12–13. X-ray tubes
14. D-c generator, 1,400 kv
15. Ion tube

100A. Standard transformer, 250 kv
1000A-B-C. Cascade transformers, 350 kv each




of ten units, each consisting of a transformer, rectifier, and capacitor connected in series to produce 1,400,000 volts direct current of either polarity with a current rating of 25 milliamperes. This can be used to supply any one of three vacuum tubes, two of which are for X rays, while the third is a source of neutrons. Smaller equipments giving 400,000 volts, 200,000 volts, and 10,000 volts will be moved into the smaller laboratories from their present location at the Bureau. Within the last few years the developments of manufacturers of X-ray apparatus have made possible the use in hospitals and laboratories of 1,000,000-volt X rays. Because of their greater penetrating power, such rays may have great utility in the therapeutic treatment of cancer and also in the examination of large metal parts for hidden flaws and cracks. This advance has reintroduced the hazard of accidental "burning" of the operator which caused so many casualties among pioneer workers in the X-ray field, and it is therefore of vital importance that the amount of protection afforded by various types of protective equipment be known quantitatively. Another and perhaps even more important group of problems in the X-ray field is concerned with the measurement of dosage. It is essential to the progress of medical science that results obtained in one hospital should be available to workers in other hospitals in definite and quantitative terms so that results obtained on different patients can be compared. This is best accomplished by the standardization of dosage meters at some one central laboratory. As the new laboratory is located within a few miles of the National Cancer Institute and of the new Navy Medical Center, it offers possibilities for a very desirable close co-operation between the medical workers in these institutions and the physicists at the National Bureau of Standards.

The equipment for use in testing voltage transformers for ratio and phase angle is based primarily on the precision shielded resistor now used at the Bureau. This is suitable for measurements up to 30,000 volts. Two 10-kva transformers rated at 100,000 volts have been used in the past to step up the precision measurements over a range of 4:1 by changes in their high-voltage connections from parallel to series. In the new laboratory a further 2:1 step-up is obtained by an additional 100-kva transformer having two high-voltage coils which may be connected in series to give a rating of 250,000 volts.

The high-voltage attracted-disk electrometer will be installed in an interior room the temperature of which can be carefully controlled. This instrument has already been used up to 100,000 volts as an independent check on the ratio measurement, and in its new quarters will be capable of use up to 300,000 volts.

An additional independent means for measuring ratio and phase angle in the upper voltage range will be secured by the use of air capacitors.

It is planned to construct a number of such capacitors in the near future. The first of these is to be of the compressed-gas type for use up to 150,000 volts, and later a free-air capacitor is planned for 250,000 volts. These capacitors will provide an additional independent means for measuring ratio and phase angle for voltage transformers, and also can be used as standards for the measurement of dielectric loss in insulation.

For testing the dielectric strength of insulating materials and the flashover voltages of insulating structures, there will be available, in addition to the 60,000-volt transformer now in use by the Bureau, three new testing transformers of 350,000-volt rating each. These transformers can be

used individually in a three-phase star connection with 600,000 volts between lines or connected in cascade to give 1,050,000 volts to ground at 60 cycles. Because of the fact that breakdown and voltage-proof tests of insulating materials and structures require only moderate precision and can be done at many commercial laboratories, the Bureau limits its testing of this nature to material purchased by various branches of the Federal Government.

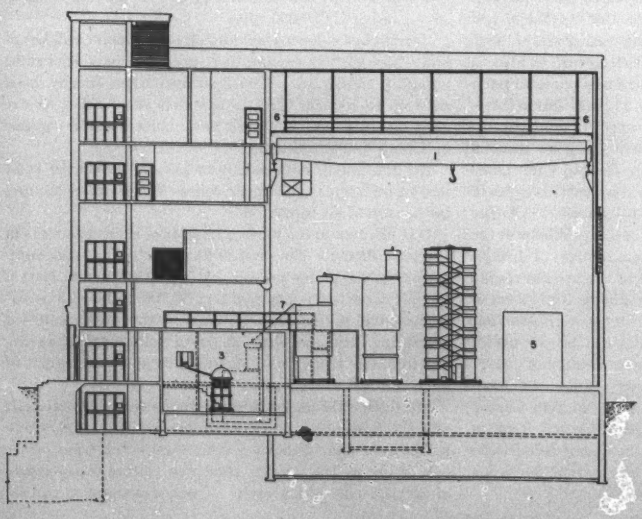
An impulse generator will also be installed in the new building. It has an energy rating of 33,000 joules, and when used with the Marx circuit a rating of 2,000,000 volts. This equipment will be so arranged that it also can be used as a source of surge currents at its charging voltage of 100,000 volts. The impulse generator and two of the cascade transformers will be mounted on trucks, so that when not in use they can be moved back against the wall, leaving more clearance for the other apparatus which is in use. A cathode-ray oscillograph of the cold-cathode type having a high writing speed will be installed for use with this impulse generator.

Extension of the scope of service of the new laboratory will be made gradually, partly because some of the equipment will not be ready for delivery before December 1940, but more especially because the available staff is limited, and because the work will lead into new and unfamiliar fields. Each step in the measurements must be based on previously tested methods and apparatus.

It is expected that the first step will be to push the precise measurement of transformer ratio up to present operating voltages of 230,000, using the electrometer, and perhaps later to check this by using an air capacitor. This probably will be followed by a study of methods for the determination of the crest voltage of sustained alternating currents, using as a standard an electrostatic method that has already been tried out on a small scale and seems capable of an accuracy approaching 0.1 per cent. This method, by reason of the small charging currents required, can then be applied in the higher voltage range to calibrate other types of crest voltmeters, including the cathode-ray oscillograph, and to determine the effective ratio of potential dividers of both the capacitance and resistance types, under a variety of conditions.

The Bureau has been active for many years in the measurement of dielectric loss in the lower-voltage range. In the new laboratory this work is expected to be extended into the range of higher voltages by using the air capacitors mentioned. A second cathode-ray oscillograph of the hot cathode type, having a sensitivity as great as three millimeters per volt, has been developed at the Bureau for the study of dielectric loss in small samples of insulating material. It is hoped that this instrument can be further developed in the new laboratory. A flexible electron optical bench has been built so that various types of electron lenses can be tried with a view toward securing the optimum conditions of focusing the electron beam. This equipment also is expected to be available for the study of focusing problems encountered in the high-voltage cold-cathode oscillograph and in X-ray tubes.

The new laboratory will enable the National Bureau of Standards to give better service both to the Federal Government and to the electrical industry, and through these agencies to the public, along the same general lines that it has given in the past. The direct service to the Government will consist to some extent of carrying out acceptance tests on insulating materials and structures purchased by the Government, but to a greater extent of special testing in connection with the development of new apparatus and the solution of unusual problems. The service to industry similarly will consist in part of the precise testing of voltage transformers and, in the future, of standards for the measurement of dielectric loss in the high-voltage range. This testing work is done for utility companies, manufacturers, and the laboratories of public-utility commissions. To an even greater extent than in the past, the service to industry is expected to include an active part in co-operative research on methods of measurement in the high-voltage range, in co-operation with technical committees of such national organizations as the American Society for Testing Materials, American Standards Association, and the AIEE.




**Transverse cross-section of laboratory, looking west**

1. Electric crane, 10 tons
3. Brooks electrometer
5. Shipping entrance
6. Walkway around walls
7. Control platform

# Analysis of World's Fairs' Hearing Tests

ONE of the popular Bell System attractions at the World's Fairs is the hearing test. A considerable percentage of the visitors to the Bell System exhibits at both the New York Fair and the Golden Gate Exposition at San Francisco have taken advantage of the opportunity to find out how well they hear and have thus made available some three-quarters of a million records.

The tests are given in soundproof rooms, and both the tests and the instructions are given through telephone receivers. Two types of tests are given, with separate booths for each. In one, the visitor hears spoken words, which are two numbers such as "eight-six," each successive pair being at a lower volume.

In the other type of test, the two numbers are replaced by pure musical tones, each tone being sounded from one to three times, and the listeners write down the number of times they hear the tone. Five tests, each consisting of nine sets of tones at successively lower volumes, are given. The first is at a moderately low pitch, 440 cycles per second; the following tests are at 880, 1,760, 3,520, and 7,040 cycles.

Only the tone tests are recorded. The word tests give only a check on one's ability to understand spoken words, while the tone test, by providing data at five frequencies over the most important part of the aural range, is more suitable for study and analysis.

The results of this survey, in harmony with previous data, indicate a definite falling off in hearing acuity with age. This is particularly noticeable at the higher frequencies. A rather remarkable fact is that at the low frequencies, the falling off with age is less for men than for women, while at the higher frequencies it is less for women than for men. These facts are indicated in figure 1 on which average hearing loss is plotted against age for two frequencies.

This difference between men and women is brought out better in figure 2, on which the hearing loss is plotted against frequency for two age groups. In the lowest age group the difference between men and women is small, but even here the advantage is slightly with the men at low frequencies and with the women at high frequencies. In the age group from 50 to 59, the difference becomes much more pronounced. In both of these illustrations, zero on the ordinate scale represents the average of both men and women in the 20–29 group.

Not all the results have been tabulated as yet, but as additional tests are examined, they are found to fall in line with those already tabulated; and there is little likelihood of any major change in trend being encountered as the tabulation proceeds. The interpretation of the losses at various frequencies is rather difficult except for specialists, since the evaluation of the effect on one's ability to hear in any particular band of frequencies is a function of many factors. It has been found, however, that one's ability to understand speech can be determined from the average of his hearing losses at 440, 880, and 1,760 cycles as compared with good young ears. If this average is 25 decibels, there may be some difficulty in hearing in auditoriums and churches, while if it is 45 decibels, there may be difficulty in hearing in direct conversation.

By use of these figures, the tests indicate that about 1 out of 25 persons has difficulty in hearing in auditoriums; 1 in 125 will have some difficulty in direct conversation; and 1 in 400 over the telephone. Two out of five men between 50 and 59 will have a loss of at least 25 decibels at 3,520 cycles, while only one in five women—half as many—will have as great a loss at this frequency. It was found, also, that about 1 in 25 of the group from 10 to 19 had a loss of at least 25 decibels at 7,040 cycles. This figure assumes importance because it has been found that young people with a hearing loss of this amount will often tend to become progressively worse in later years, but that if remedial measures are taken immediately, the hearing impairment may be largely checked.

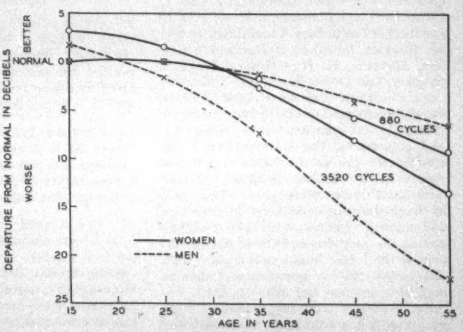



**Figure 1. Variation in hearing loss with age for men and women at 880 and 3,520 cycles**

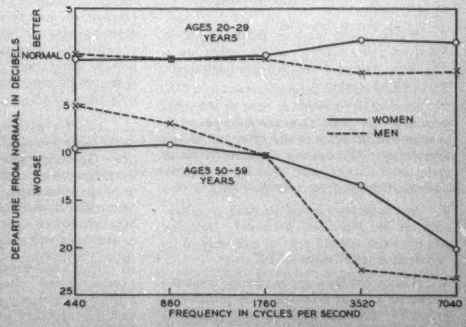



**Figure 2. Variation in hearing loss with frequency for men and women in the age groups 20–29 and 50–59**

Excerpts from an article of the same title by H. C. Montgomery, acoustical research department, Bell Telephone Laboratories, Inc., New York, N. Y., and published in the *Bell Laboratories Record*, December 1939, pages 98–103

# Of Current Interest

## Forum of Youth and Industry

"OPPORTUNITY for youth in building the World of Tomorrow" was the theme of a dinner meeting held by the General Motors Corporation, May 6, 1940, in the company's exhibit building at the New York World's Fair. The meeting was attended by several hundred invited guests, including college students, presidents, and faculty members from some 80 representative eastern, southern, and middle-western colleges, as well as from several General Motors apprentice and training schools.

The prearranged after-dinner program included talks by Alfred P. Sloan, Jr., chairman of the board, William S. Knudsen, president, and Charles F. Kettering (A'04, F'14), vice-president in charge of research, of General Motors. The program also included a panel discussion of specific student questions which were answered by Karl T. Compton (F'31), president of Massachusetts Institute of Technology, Cambridge; Ernest M. Hopkins, president of Dartmouth College, Hanover, N. H.; General Hugh S. Johnson; and Doctor Kettering.

Each student had been asked prior to the dinner to send in one or two questions. Hundreds of questions were submitted, and a group of the most pertinent was selected for use in the forum which was conducted by Clifton Fadiman, literary critic and radio personality. This part of the program was conducted in "question and answer" fashion, with Mr. Fadiman stating the questions and one or more members of the forum board answering. With the thought that the questions and answers may be of interest and value to AIEE Enrolled Students, they are presented here; no attempt has been made to record verbatim answers, but the summarizing answers are believed to embrace the essential substance of those given. The person answering is indicated by initials at the end of each answer.

1. *Which counts more in getting a job—a letter on your sweater, or the letters on a Phi Beta Kappa key?* No good employer will look at either—HSJ.

2. *We face the paradox of want in the midst of plenty. Is youth's answer to be found in government action or in the efforts of private enterprise?* The answer appears to be in government action now, but try a slightly divergent course from now on—HSJ.

3. *Has industry reached its peak of expansion, or are there new horizons?* Industry has not even started yet; is now only in its "covered wagon" days—CFK.

4. *What about the profit motive—is there any substitute for it as a vital force in stimulating progress?* INTELLIGENT self-interest is the best motive in stimulating progress; it is possible even to love money INTELLIGENTLY—EMH.

5. *If technological improvement continues will not more and more men be thrown out of work as time goes on?* No. Every new thing developed creates more jobs. Although technological improvement may create unemployment in specific instances, in general it creates many more jobs than it destroys—KTC.

6. *Is it still possible to jump many rungs on the way up the ladder by marrying the boss' daughter?* Don't jump too many rungs; the ladder might break—CFK.

7. *Is it reasonable to expect expansion in industry alone to absorb the millions reported as unemployed, plus college and high-school graduates?* Of course; the only question is in getting started—CFK. (HSJ cited statistics in support of this answer.)

8. *Are the chances greater with a large institution or with a small, more personalized company?* Depends on the individual capacities and tendencies; some men progress faster with large companies, and others with smaller organizations—HSJ.

9. *If business and industrial expansion were free to follow its natural course would it be sufficient to absorb our idle men, money, and materials?* It would go a long way toward achieving that end—KTC.

10. *Can a young man of intelligence but little formal education work his way to the top or is a college education becoming a prerequisite to high executive leadership?* Formal education not necessary; may even be harmful to some men—EMH. Although a formal education is not necessary, the man with formal education has far better chances—KTC.

11. *Would there be more jobs for youth if industrial activities were planned under government supervision?* We must have more government regulation, but not substitution of governmental enterprise for private enterprise; governmental regulations should prevent abuses, but not stifle initiative—HSJ.

12. *Can I capitalize on a college education in the factory or should I hold out for an office job?* Graduates must have experience and learn how to get along with people in order to progress in either type of job; a college education is valuable both places—CFK. Most graduates want shop jobs first in order to obtain experience—KTC.

13. *With increasing relationship between government and industry isn't there a need in government service for young men equipped with a background of industrial experience?* Definitely yes. Unfortunately the trend is now in the other direction, probably because of the lower salary ceilings in government—KTC. Our government doesn't reward government leaders properly—HSJ.

14. *What about social prestige as help in getting ahead in business and industry?* Ability is most important, especially in higher executive positions—KTC.

15. *What can industry do toward raising the standard of living by making it possible for more people to buy more?* More people must produce more and to do that must produce more efficiently—KTC.

16. *Is it fair for business and industry to ask a college graduate to start at the same pay as any other beginner?* No. Because of his better training and equipment the college graduate should receive more—KTC. As in any other race, the stronger man should be willing to give a "handicap"; and since his chances to succeed are better, the college graduate should be willing to start at the lower salary—HSJ.

17. *Are there opportunities in industry for graduates from a general arts course?* Liberal-arts graduates are more common in executive positions—EMH.

18. *Who is going to pay for all those new roads shown in the Futurama?* These kids here—HSJ.

19. *Mr. Knudsen's booklet "If I Were 21" advises us to work with our hands but I have absolutely no mechanical aptitude. What should I do about it?* Most cases of "lack of mechanical aptitude" are only lack of practice or fear, neither of which constitute true lack of mechanical aptitude—CFK.

20. *To what extent is the technical student limited to his particular specialization after entering industry?* About 50 per cent of technical graduates follow the specialties of their training; the other 50 per cent are found in all other types of positions—KTC.

21. *Does industry prefer to train men directly out of college or is graduate training (such as is given by schools of business administration) more desirable?* Graduate training helps some men in some jobs; but not every man is benefited by graduate training or even by any college training at all—EMH.

22. *Can I get along as well in business if I follow high social and ethical standards as I could if I didn't?* NOBODY gets along in ANY stratum of society on low standards—HSJ.

23. *Are there any changes needed in our educational system to prepare youth more adequately for business and industry?* Changes are always needed—EMH. Changes are needed to keep the educational program up to date, and to keep the teachers alive—KTC.

### DOCTOR KETTERING CITES NEED FOR NEW PROJECTS

Doctor Kettering, whose address constituted the concluding event of the evening,

warned that any attempt to chart the future was impossible. Pointing to the inability of past generations to forsee the tremendous advances of modern industry, he told the students it was equally futile "for us to try to imagine what the future will be, let alone plan it. All we can do is prepare ourselves to take full advantage of what the future will bring. Our over-all ability is the only thing that really counts.

"We have excesses of men, money, and materials," Doctor Kettering said. "All that we lack today are new projects—new inventions, new products, new activities.

"We need new things more than ever before. With our excess of men, money, and materials, we need new opportunities to put them to work. The discovery of a few fundamental facts might easily be the basis for new industries which will keep us all busy for years to come, just as they have in the past."

# Honors • • • •

## Egleston Medal Awarded for 1940

The 1940 Egleston Medal of the Columbia University School of Engineering has been awarded to Grover Loening, president of the Grover Loening Aircraft Company, Garden City, N. Y., inventor of the strut-braced monoplane, and holder of many airplane patents. He received the degree of civil engineer from Columbia in 1911.

Founded in 1939, the Egleston Medal is awarded annually to a Columbia alumnus for distinguished engineering achievement (*EE, Jan. '40, p. 44*). The medalist is chosen by the board of managers of the Engineering Alumni Association, of which A. Dexter Hinckley (A'27, M'38) assistant to the dean of the engineering faculty, Columbia, is executive secretary.

## Franklin Institute Awards

Presentation of 1940 medal awards by the Franklin Institute was made May 15, 1940, at "Medal Day" exercises in Philadelphia, Pa., which were followed by a dinner in honor of the medalists. The medals presented and the recipients are as follows:

*Franklin Medal*—A. H. Compton, University of Chicago, for his experiments on properties of X rays and in particular for his discovery of the "Compton effect"; L. H. Backeland, retired president, The Bakelite Corporation, New York, N. Y., for contributions to improvement of the industrial arts and in particular for the invention and manufacture of Bakelite.

*Elliott Cresson Medal*—F. M. Becket, president, Union Carbide and Carbon Research Laboratories, New York, N. Y., for developments in production of low-carbon ferro alloys, and also for contributions in electrometallurgy; R. R. Williams, Bell Telephone Laboratories, New York, N. Y., for researches upon vitamin $B_1$.

*Louis E. Levy Medal*—jointly to Charles Rosenblum, Princeton University, and J. R. Flagg, University of Rochester, for their paper "Artificial Radioactive Indicators".

*George R. Henderson Medal*—W. E. Woodard, Lima Locomotive Works, Inc., New York, N. Y., for contributions in steam locomotive design.

*John Price Wetherill Medal*—Laurens Hammond, president, Hammond Instrument Company, Chicago, Ill., for the inventive skill displayed in the development of the Hammond organ; jointly to E. E. Kleinschmidt (M'22) president, Kleinschmidt Laboratories, Highland Park, Ill., and H. L. Krum (A'12, F'27) (Teletype Corporation, Chicago, Ill.) Beverly Hills, Calif., for their part in the development of the teletypewriter.

*Edward Longstreth Medal*—jointly to Leopold Godowsky, Jr., and L. D. Mannes, Eastman Kodak Company, Rochester, N. Y., for development and processing of Kodachrome film; Games Slayter, Owens-Corning Fiberglas Corporation, Newark, Ohio, for improved methods and apparatus for making spun and blown glass filaments; R. C. Templin, Aluminum Company of America, New Kensington, Pa., for the development of the Templin automatic autographic deformation recorder; M. M. Upson, president, Raymond Concrete Pile Company, New York, N. Y., for contributions to the scientific development of foundation engineering and construction.

*Certificate of Merit*—jointly to G. H. Ernsbarger, Honolulu, T. H., and F. L. McCarty, Ogden, Utah, for development of a device for loading a jigging conveyor.

### ATLANTIC REFINING COMPANY HONORED

For its pioneer work in relation to refining, transporting, and marketing petroleum products, the Atlantic Refining Company, Philadelphia, Pa., was honored at a dinner given by the Franklin Institute, April 29, 1940.

Among the achievements noted on the citation presented to the company is "novel developments in the construction and propulsion of ocean-going tankers."

These steam-turbine-electric ships are unique in that, contrary to marine tradition, both practices and equipment common to modern land power plants were utilized. These included high-pressure (625-pound 835-degrees-Fahrenheit) boilers, standard turbine generators (4,500 kw, 60 cycles, 2.3 kv at 3,600 rpm), synchronous-induction propulsion motors (5,000 shaft horsepower at 90 rpm, 2.3 kv, three phase), deep-well cargo pumps (300 horsepower, 2.3 kv, 1,750 rpm), and induction motors for steering-gear oil pumps.

**Awards for "Amplidyne" Development.** Charles F. Coffin Foundation Awards, conferred annually by the General Electric Company upon employees for outstanding contributions to the company and the electrical industry, recently were given to Kenneth K. Bowman, M. A. Edwards, and Francis Mohler, for improvements in control equipment made possible by the development of the "amplidyne" generator. Three papers on this subject were presented at the industrial power applications session of the AIEE winter convention, New York, N. Y., January 22–26, 1940, and will be published in the AIEE TRANSACTIONS. Mr. Edwards was co-author of two of the papers and Mr. Bowman co-author of one.

# Education • • •

**Stevens Management Conference.** The tenth of the series of annual conferences of business and engineering administrators held by Stevens Institute of Technology, Hoboken, N. J., at its Engineering Camp at Johnsonburg, N. J., is to be a management conference, to be held June 22–30, 1940. Four series of morning conferences, two of which may be attended without conflict of hours will deal with management control industrial psychology, applied economics, and labor. Evening discussion sessions will be held for the entire group. The conference will be limited to 50 full members, 50 associates each nominated by a full member, and a group of teacher members. The advisory committee planning the conference includes R. M. Gates (M'35) vice-president, The Superheater Company, New York, N. Y.; L. M. Goldsmith (M'26) chief engineer, Atlantic Refining Company, Philadelphia, Pa.; H. A. Wagner (A'98, M'03) president, Consolidated Gas Electric Light and Power Company of Baltimore, Md.

**Traffic Engineering Fellowships.** Two groups of graduate fellowships in street and highway traffic engineering are available at the Bureau for Street Traffic Research, Yale University, according to an announcement by the Bureau. Only employees of state highway departments are eligible for 7 of these fellowships; for 12 others, employees of organizations concerned with engineering aspects of traffic control, or graduate students seeking a career in traffic engineering, may apply. Applicants should write to Maxwell Halsey, associate director, Bureau of Street Traffic Research, Room 311, Strathcona Hall, Yale University, New Haven, Conn.

**Industrial Statistics Course.** A two-weeks summer course in statistical methods is being offered by Massachusetts Institute of Technology, September 4–14, 1940. The course is intended for those interested in applying the rudiments of modern statistical technique to design and analysis of laboratory experiments and control of the quality of industrial products. Registration is limited to 20 persons, to be accepted in the order of application.

# Other Societies •

## Valuation Engineers Organize National Society

Planned as a national organization of valuation engineers, the Technical Valuation Society, Inc., was organized and chartered under New York State laws in December 1939 and has established headquarters at 60 Wall Street, New York, N. Y. Its constitution and bylaws are modeled to a considerable extent upon those of the older national engineering societies, particularly in regard to grades of membership, application procedure, and provision for geographical districts.

Objects of the society as stated in its constitution are:

"To establish the recognition of valuation engineering as a professional degree; to promote the intercourse of engineers among themselves and to foster the relations of the accounting branches of valuation work and with official governing bodies; to advance the standard of valuation engineering; to foster valuation-engineering education; and in cooperation with other engineering, technical, and accounting societies to broaden the scope of the valuation engineer."

## Chemical Groups Hold Electrical-Insulation Symposium

A symposium on electrical insulation was held as one of the sessions of the annual meeting of the American Chemical Society, Cincinnati, Ohio, April 8–12, 1940. Sponsored by the society's division of industrial and engineering chemistry, the symposium was arranged by the subcommittee on chemistry of the Conference on Electrical Insulation, National Research Council. Of the five papers presented, one, "Dielectric Properties of the Rutile Crystalline Modification of Titanium Dioxide" by L. J. Berberich (A'30, M'36) and M. E. Bell, was also presented at the annual meeting of the Conference on Electrical Insulation, Cambridge, Mass., November 2–4, 1939, and an abstract published in ELECTRICAL ENGINEERING, January 1940, page 33. Brief abstracts of the other papers follow:

**Electrical Insulating-Oil Deterioration: Chemical and Electrical Tests,** *J. C. Balsbaugh (A'23, M'35), A. H. Howell (A'35), A. G. Assaf.* Studies of the electrical and oxidation stability of two series of related samples of electrical insulating oils have been made. One consists of 11 samples, representing different solvent refining extracts and finishing treatments, from an appropriate distillation cut; the other of 5 samples with varying amount or aromaticities, one of the samples being aromatic-free. These samples were deteriorated by oxidation in the presence of paper and copper in an improved deteriorating system consisting of an all-glass enclosed system, an automatic means for maintaining constant oxygen pressure, and small platinum-tubing cells for making electrical measurements on the oil and the oil-impregnated paper during the deterioration. The results show that the electrical stability and the oxidation stability of an oil are differently affected by the initial chemical constituency and the refining of an oil, and that the electrical loss as a function of oxidation time or oxygen absorbed may start with a rapid increase to a relatively high value to be followed by an equally rapid decrease to a relatively low value with further oxygen absorbed, after which the loss again increases with continued oxidation.

**The Dielectric Properties of Some Organic Compounds As Related to Chemical Composition and Physical Structure,** *S. O. Morgan, W. A. Yager.* The dielectric constants of polar liquids should be directly derivable from their chemical structure according to simple dielectric theory. In many liquids the observed values differ greatly from those thus calculated. These departures may be due to association or interaction causing the molecules to act as associated pairs or aggregates in which the net electric moment is low because dipoles are so directed as to oppose each other. Also, such differences may be due to the effect of internal friction or viscosity in restricting the motion of dipoles or to solidification which may entirely prevent motion. In the solid state, where on the basis of simple theory no rotation would be expected and consequently low dielectric constants would be the rule, there are many cases of high dielectric constant. The geometry of the molecule is the determining factor in permitting rotation of molecules and high dielectric constant in the solid state. In plastics the polymer molecules as a whole are too large to rotate but motion of polar groups may be possible. Such motions appear to be sufficient to explain observed values of dielectric constant in plastics. A correlation is found between the presence of polar groups and value of dielectric constant in plastics.

**The Electric Conduction in Dielectric Liquids,** *R. W. Dornte.* The current-voltage relations at high electrical gradients were obtained for dry gas-free heptane and benzene at 23 degrees centigrade. The current measurements were made in both uniform and nonuniform electric fields which were obtained by the use of plane parallel, hemispherical, and concentric cylindrical electrodes. A comparison of the experimental results with the requirements of the thermionic emission theory of conduction was made by means of the slopes of the current-voltage curves. The agreement of the experimentally determined slopes with those calculated by this theory is not satisfactory. The experimental result was generally greater than the calculated slope, indicating that the electron emission was concentrated on sharp points on the electrode surface. This conclusion was substantiated by experiments showing that the currents were not proportional to the electrode areas in uniform electric fields. The current-voltage curves were dependent upon the nature of the electrode surfaces and were influenced by the polish and adsorbed gases, as well as materials which were removed from the cell by repeated washings with the purified benzene or heptane. The current-voltage characteristics of benzene and heptane were reproducible in a given cell but were difficult to produce in different cells. The slope of current-voltage characteristic for heptane was independent of the temperature in the interval 23 to 97 degrees centigrade. The cold-cathode emission of electrons is suggested as a possible mechanism for the electrical conduction in dielectric liquids. In a nonuniform electric field the current was not determined by the voltage gradient at the cathode as required by either of these conduction mechanisms.

**Conductivity in Insulators and Its Interpretation,** *A. von Hippel (M'37).* The electrostatic classification of matter into conductors and insulators no longer can be vindicated. In every insulator, charges may be transported; the degree of conduction depends not only upon the chemical material used but also upon the treatment it is given, its temperature, the strength and duration of the electric field to which it is subjected, its previous history, and even the metal electrode in contact with it. The paper tries to resolve this complexity of phenomena into a number of elementary processes, for which experimental examples are given. In this way a new understanding of dielectric matter can be built up which should prove helpful for chemical and physical research.

### *Future Meetings of Other Societies*

**American Association for the Advancement of Science.** Summer meeting, June 17–22, 1940, Seattle, Wash.

**American Chemical Society.** Fall meeting, September 9–13, 1940, Detroit, Mich.

**American Institute of Mining and Metallurgical Engineers.** Regional meeting, September 10–13, Salt Lake City, Utah.

**American Physical Society.** 235th meeting, June 19–20, 1940, Seattle, Wash.

236th meeting, June 20–22, 1940, Pittsburgh, Pa.

**American Society for Testing Materials.** 43d annual meeting, June 24–28, 1940, Atlantic City, N. J.

**American Society of Civil Engineers.** Annual convention, July 24–26, 1940, Denver, Colo.

**American Society of Heating and Ventilating Engineers.** Semiannual meeting, June 17–19, 1940. Washington, D. C.

**American Society of Mechanical Engineers.** Semiannual meeting, June 17–21, 1940, Milwaukee, Wis.

Applied mechanics division, June 20–21, 1940, Ann Arbor, Mich. Oil and gas power division, June 19–21, 1940, Asbury Park, N. J.

Fall meeting, September 3–6, 1940, Spokane, Wash.

**American Transit Association.** 59th annual convention, September 23–26, 1940, White Sulphur Springs, W. Va.

**Illuminating Engineering Society.** 34th annual convention, September 9–12, 1940, Spring Lake, N. J.

**Institute of Radio Engineers.** 15th annual convention, June 27–29, 1940, Boston, Mass.

**Society for the Promotion of Engineering Education.** 48th annual meeting, June 24–28, 1940, University of California, Berkeley, Calif.

**ASTM 1940 Index Issued.** The 1940 edition of the "Index to ASTM Standards, Including Tentative Standards", recently issued by the American Society for Testing Materials, contains information as of January 1, 1940, on the society's 885 standards. Copies of the 152-page publication may be secured without charge from the society's headquarters, 260 South Broad Street, Philadelphia, Pa.

**Research Institute Meets.** Member representatives of the Industrial Research Institute, affiliate of the National Research Council, met with deans of engineering from a number of American universities at the Institute's annual meeting at Cincinnati, Ohio, April 26–27, 1940. Feature session of the meeting was a panel discussion on how to make industry and university relations in research more effective.

# Industry • • • •

## Lighting Practice

The Illuminating Engineering Society has just issued "Recommended Practice for the Illumination Performance of Residential Ceiling Luminaires", prepared by its committee on residence lighting. Recommendations cover standards of performance, but do not include construction specifications.

The number of variable factors affecting the efficiency of lighting fixtures makes issuance of detailed construction rules impracticable, although the society made one exception in the case of its specifications for

a portable reading lamp, issued in 1934. The recent report points out that most-favorable seeing conditions are usually provided by a combination of general and special lighting.

A new edition of "Artificial Light and Its Application", 296-page source book, has recently been published by the lamp division of the Westinghouse Electric and Manufacturing Company. The book covers a wide range of lighting applications, including residence lighting. Copies may be obtained for $1.25, or single chapters for 7 cents each, from the company, 150 Broadway, New York, N. Y.

**Cathode-Ray Contest.** A prize contest for new practical applications of the cathode-ray tube and allied equipment will be conducted by the Allen B. Du Mont Laboratories, Inc., Passaic, N. J., from June 1, 1940, to May 31, 1941. Entries may be made by anyone, at any time during the period, and in any number, but only papers dealing with actual applications will be considered. Applications may be in any field. Prizes of $100, $50, and $25 will be awarded for the three best papers submitted, and $10 will be paid for papers accepted for publication in the Du Mont *Oscillographer*.

**Report on Industrial Dermatitis.** The National Association of Manufacturers' committee on healthful working conditions has issued a summary of accepted medical knowledge on the subject of industrial dermatitis, which in some form is the cause of more than half the compensation claims for occupational disease. Single copies of the report may be secured free, or quantities at cost, from the committee, at 14 West 49th Street, New York, N. Y.

average cost of 4.20 cents. Commercial and industrial users numbering 3,689,477 paid $1,069,932,195 for 59,182,940,000 kilowatt-hours, an average of 1.81 cents per kilowatt-hour.

The Commission has ordered 31 utility companies to show cause for their failure to comply with provisions in its uniform system of accounts requiring the reclassification of plant accounts on the basis of original cost.

## Supreme Court Stops Sale of Hetch-Hetchy Power

Final settlement of a dispute between the Federal Government and the city of San Francisco that dates back to 1923 was rendered when the United States Supreme Court on April 22 declared invalid a contract between the city and the Pacific Gas and Electric Company for the distribution of electric power generated as a by-product of the Hetch-Hetchy municipal water development.

In 1913 Congress authorized the city to use lands included in the Yosemite National Park and the Stanislaus National Forest as a source of its water supply on condition that none of the power to be generated as a by-product should be sold to any corporation or individual except a municipality or water or irrigation district. As a temporary measure, the city contracted with the power company to act as its agent in transmitting and distributing the power, and has continued this arrangement ever since.

In 1923, and at intervals thereafter, the Federal Government has warned the city that this agreement violates the conditions imposed, and San Francisco has several times held elections on the question of establishing a municipal power system, but this proposal has each time been defeated. The latest of these was in 1937, after Secretary of the Interior Harold L. Ickes had warned the city to cease violating the act of 1913. Whereupon the Federal Government applied to the courts for an injunction prohibiting further operation of the power plants. This was granted by a District Court, overruled by a Court of Appeals, and has now been sustained by the Supreme Court.

The practical effect of the decision is to force San Francisco to choose immediately between setting up a municipal power system or ceasing to operate the Moccasin and early Intake power plants in the Hetch-Hetchy valley.

## More Utilities Contest "Death Sentence"

Efforts of the Securities and Exchange Commission to break up large and complex holding-company structures in accordance with provisions of the Public Utility Holding Company Act of 1935 are meeting with continued resistance on the grounds of unconstitutionality of the statute. In addition to the Engineers Public Service Company (noted last month) three other organizations have replied to SEC orders to submit reorganization plans with this same contention. These are Electric Bond and Share Company, United Gas Improvement Company, and Commonwealth and Southern Corporation.

United Gas Improvement Company has also attacked SEC's method of procedure; it contends that instead of directing holding companies to submit plans for reorganization the agency first should have prepared its own plans, which then should have been reviewed in public hearings.

# From A E C • •

ITEMS appearing under this heading are from the news service of American Engineering Council.

## FPC Publication Details Utility Statistics

Comprehensive facts regarding all public-utility companies in the United States receiving annual electric incomes of $250,000 or more, representing 95 per cent of the industry, are contained in a new publication of the Federal Power Commission, "Statistics of Electric Utilities in the United States, 1938" available at $2 per copy from the Commission. The 500-page volume reports official figures from detailed returns made to the Commission as required by law. A similar volume was issued last year.

The 393 electric-utility companies listed have total assets aggregating $17,220,617,262; utility-plant accounts totaling $14,048,019,026; outstanding securities amounting to $13,546,254,340. In 1938 their electric operating revenues aggregated $2,168,670,032 from the following sources: 19,411,872 residential customers paid $683,341,136 for 16,285,671,000 kilowatt-hours, an average use of 839 kilowatt-hours at an

# Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

## Post-Convention Cruise

*To the Editor:*

The post-convention cruise was a success in program if not in numbers. The astounding number of three accepted the rigors of the cruise, and risked life and limb against the wind, the sea, and submarines. Those participating were: Mrs. Julia Mullaney, of New York City and Daytona Beach; Miss Mildred Clark, of Orange, N. J.; and the writer.

The SS George Washington left New York at 1:00 p. m. Saturday, January 27, and arrived in Norfolk the following morning. There were about 90 passengers aboard, about half of whom were United States Navy recruits going to the medical training school in Portsmouth, Va. The group certainly spoke well for the exceptionally high type of young men entering the services at the present time. All went smoothly until about 9:00 p. m. when the wind howled and the boat rocked and the waves did beat themselves against the hull, and caressed the portholes and first deck. Many succumbed, but the little group of three stood firm and resolute. Came the dawn, and with it, a beautiful day and a calm sea for the remainder of the trip.

Upon arriving at the wharf, the ship's employees had a little difficulty in placing the gangplank at the correct angle, but finally succeeded in making it into an Alpine climber's nightmare, and the passengers struggled ashore. The AIEE group was met here with a car and two guides—one to drive and the other to lecture—due to the presence of ice and snow on the highways. The tour included Norfolk, Newport News, Old Point Comfort, Jamestown, and Williamsburg. At Newport News, there were the shipyards; at Old Point Comfort, Fortress Monroe and the Chamberlain Hotel; at Jamestown, the statues of John Smith and Pocahontas. as well as the original church

tower dating from the first settlement at Jamestown in 1607. The graves of many historic persons are in the old church, which has been restored to its former condition.

At Williamsburg, lunch was served at the Inn, and after lunch the tour continued with a visit to the restored buildings of colonial times. These are new brick buildings built on the same plans as the originals. Inside are the offices, committee rooms, and assembly halls of the rulers of the Jamestown colony. The furnishings are in accordance with inventories which have been discovered from time to time in colonial records, and in cases where original pieces were not obtainable, reproductions have been wrought with painstaking care. There were beautiful glass chandeliers, furniture of fine woods, exquisitely fashioned silver fixtures and tableware, and fine porcelains, draperies, and rugs. For any one interested in antiques of early colonial times, Williamsburg is well worth seeing. In fact, after going through these buildings and viewing the furnishings, and seeing the hostesses clothed in period costume, the visitor begins to feel that he himself is back in that early time, and is mildly shocked to see a hostess reading a modern magazine!

After spending about three hours in Williamsburg, it was time to continue back to Virginia Beach where the hotel was waiting. And what a hotel! A swimming pool, sumptuous meals, luxurious rooms, and the best of service. The party stayed over night at the hotel, and had the following day free for visiting the shops in Norfolk, walking along the snow-swept beach, or just enjoying the comfort of the hotel. At four in the afternoon, the car returned to the hotel in order to take the group to the ship for the return voyage. It was with many regrets that the wharf was seen to slip away into the darkening shadows of the night, and the crunching of ice in the outer harbor was heard.

The sail up to New York was as calm as a mill-pond, and finally the hustle and bustle of the great harbor was seen. It was like living in the past and suddenly coming face to face with the fast tempo of the present. A thoroughly worth-while trip, and it was extremely regrettable that more could not disregard the possibly unseasonable weather, and take it. If they knew what they were missing, they would have overlooked wind, tide, and storm.

A. M. SALISBURY (A'37)
(Westfield Gas and Electric Company, Westfield, Mass.)

## "Reciprocal Addition"

*To the Editor:*

Those who handle reciprocals in making calculations for parallel resistors or series capacitors may find the following mathematical device of interest:

Let it be desired to find the parallel resistance of three resistors, of 1 ohm, 2 ohms, and 3 ohms, respectively. By the standard procedure, the total conductance is given by

$$\frac{1}{1}+\frac{1}{2}+\frac{1}{3}=\frac{6+3+2}{6}=\frac{11}{6}\text{ mhos}$$

Hence the resistance is 6/11 ohms.

By introducing a new symbolism, the necessity of considering conductances or reciprocals is avoided, and the procedure is considered as a special type of addition of fractions, that is, "reciprocal addition." As in other symbolic innovations, the actual numerical work is not lessened, but the amount of writing is decreased, and thinking may be clarified somewhat.

Let us define the symbol

$$\text{Recip}(R_1R_2R_3R_4\ldots)\equiv \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_4}+\ldots}=R$$

In the above example, then,

$$R=\text{Recip}\,(1,2,3)=\text{Recip}\left(\frac{1}{1},\frac{2}{1},\frac{3}{1}\right)=\text{Recip}\left(\frac{6}{6},\frac{6}{3},\frac{6}{2}\right),$$

and by adding the *denominators*, we get directly 6/11 ohms.

The procedure is therefore: (1) expression of each term in fractional form, (2) reduction to the *least common numerator*, and (3) addition of the *denominators*.

For a demonstration in general terms, let $\prod_1^n R_i$ represent the product of $R_1$ to $R_n$. Then

$$\text{Recip}(R_1R_2\ldots R_n)=\text{Recip}\left(R_1\frac{\prod_1^n R_i}{R_1R_2\ldots R_n},\ R_2\frac{\prod_1^n R_i}{R_1R_2\ldots R_n},\ \ldots\ R_n\frac{\prod_1^n R_i}{R_1R_2\ldots R_n}\right)=$$

$$\text{Recip}\left(\frac{\prod_1^n R_i}{R_2R_3\ldots R_n},\ \frac{\prod_1^n R_i}{R_1R_3\ldots R_n},\ \ldots\ \frac{\prod_1^n R_i}{R_1R_2\ldots R_{n-1}}\right)$$

and applying step 3,

$$\text{Recip}(R_1R_2\ldots R_n)=\frac{\prod_1^n R_i}{R_2R_3\ldots R_n+R_1R_3\ldots R_n+\ldots+R_1R_3\ldots R_{n-1}}=$$

$$\frac{1}{\frac{R_2R_3\ldots R_n}{\prod_1^n R_i}+\frac{R_1R_3\ldots R_n}{\prod_1^n R_i}+\ldots+\frac{R_1R_2\ldots R_{n-1}}{\prod_1^n R_i}}=$$

$$\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\ldots+\frac{1}{R_n}}$$

ELLIS BLADE (A'35)
(Technical consultant, John Chatillon and Sons, New York, N.Y.)

## The Use of the Millibar in Weather Bureau Reports

*To the Editor:*

This has reference to the letter by Clayton H. Sharp, in ELECTRICAL ENGINEERING, March 1940, page 124.

The engineering societies should commend the Weather Bureau for their adoption of the international standard "millibar" because it is in line with modern progress.

Nothing deserves to be retained merely because it is "ancient." Each thing should stand on its own inherent merits. The millibar has the advantages of logic; it is scientifically correct; it is convenient to use, and is really an international standard.

The cgs system of units and the metric system are not "theoretical" but very practical, as I know by my own use for many years.

The Weather Bureau is to be supported in the move to use more widely the international units and it is to be hoped that none of the great engineering societies will make the mistake of opposing this real progress.

ARTHUR BESSEY SMITH (A'04, F'22)
(Chief research engineer, Associated Electric Laboratories, Inc., Chicago, Ill.

## "Electromagnetic Problems in Electrical Engineering"

*To the Editor:*

One who has occasion to read widely in electromagnetic theory as concerns its application in electrical-machine design cannot help but note how little, comparatively speaking, has been done in connection with field-mapping problems in regions containing two or more materials of different permeabilities. Among the major contributors to this field have been G. F. C. Searle, W. Rogowski, T. Lehmann, E. Roth, and B. Hague. The subject is summarized in the latter's unique and important "Electromagnetic Problems in Electrical Engineering" which is, practically speaking, the only reference book in this branch of electrical engineering. For this very reason errors in this text are of special concern. It is the purpose of this letter to point out one such, rendered the more important by the fact that this incorrect formula has been used by others.

On pages 275–9 Hague discusses the problem: Given an isolated linear conductor of radius $a$ and permeability $\mu$ contained in a medium of unit permeability, carrying a direct current of magnitude $I$ and density $\delta$, to find the vector potential interior and exterior to the conductor. The solution given,

$$A_e=-2I\left(\log\frac{r}{a}+\frac{1}{2}\right)\quad\text{when } r>a$$

$$A_i=-\mu I\frac{r^2}{a^2}\qquad\text{when } r<a$$

is incorrect.

It is not difficult to find Hague's error. On page 276 it is stated that

> "Again, at $r=a$ the vector potential in the air must be $\frac{1}{\mu}$ times that in the permeable rod; in other words, the induction, in this problem entirely peripheral, must be discontinuous on the two sides of the boundary since the normal or continuous component of $B$ is zero thereat."

This is not true. At a given point on an interface between two media of different permeability, the vector potential* in each

* See for example, STATIC AND DYNAMIC ELECTRICITY, W. R. Smythe, page 280, equation 3.

medium is the same, and is always so regardless of whether or not the induction is totally tangential (as in this case).

In pages 278–9 Hague gives a second solution which is also incorrect. Here the total current is considered to be an aggregate of parallel current filaments and the total vector potential is obtained by summing the vector potentials due to each of the individual filaments. But in doing so one is no longer dealing with a filament in a medium of permeability $\mu$ but rather with a filament in a medium of permeability $\mu$ surrounded by another of unit permeability and the interface between these two produces magnetic effects which are completely neglected in the treatment of the book. Although the effects so produced cancel when all filaments are treated, the procedure of the solution is misleading and will give incorrect solutions when applied to conductors of other shapes. The solution obtained by this method agrees with that obtained by the first method because the erroneous boundary solution is again used. On page 278 we have,

"When $P$ is inside the section of the bar $\mu$ is retained; when $P$ is outside the section the right-hand side is divided by $\mu$."

The correct solution of this problem is the following. We seek a solution $A$ which satisfies the following conditions:

$$(a).\quad \frac{d^2A_i}{dr^2}+\frac{1}{r}\frac{dA_i}{dr}=-4\pi\mu\delta \qquad \text{when } r<a$$

$$(b).\quad \frac{d^2A_e}{dr^2}+\frac{1}{r}\frac{dA_e}{dr}=0 \qquad \text{when } r>a$$

$$(c).\quad \frac{1}{\mu}\frac{dA_i}{dr}=\frac{1}{\mu}\frac{dA_e}{dr} \qquad \text{when } r=a$$

$$(d).\quad A_i=A_e \qquad \text{when } r=a$$

$(e)$. $A$ is finite within the conductor.

Now $(a)$ and $(b)$ are well-known equations, and solutions satisfying $(e)$ are:

$$A_i=-\delta\mu\pi r^2+C_1$$
$$A_e=C_2\log r+C_3$$

To determine the constants we employ $(c)$ and $(d)$ together with the stipulation, the datum of $A$ being arbitrary, that $A_i=0$ when $r=0$. Applying these conditions and recalling that $\pi r^2\delta=I$ we obtain

$$A_e=-2I\left(\mu\log\frac{r}{a}+\frac{\mu}{2}\right) \qquad \text{when } r\leq a$$

$$A_i=-\mu\frac{Ir^2}{a^2} \qquad \text{when } r\geq a$$

If $\mu=1$ we obtain the correct solution of Hague's problem.

$$A_e=-2I\left(\log\frac{r}{a}+\frac{\mu}{2}\right) \qquad \text{when } r\leq a$$

$$A_i=-\mu I\frac{r^2}{a^2} \qquad \text{when } r\geq a$$

Comparison of this solution with that given by Hague reveals a difference in the expression for $A_e$.

THOMAS J. HIGGINS (M'40)

(School of electrical engineering, Purdue University, West Lafayette, Ind.)

# Books Received

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

THE HISTORY OF THE INSTITUTION OF ELECTRICAL ENGINEERS (1871–1931). By R. Appleyard. Institution of Electrical Engineers, Savoy Place, London, 1939. 342 pages, illustrated, tables, 10 by 7½ inches, cloth, 18s6d. The history of the Institution, as here presented, is an account of the development of electrical engineering during 60 active years. In that development the Institution has played an important part, and this record of its work, the matters discussed by it, and the eminent engineers who were members, is a valuable contribution to engineering history.

THE MEASUREMENT OF ALTERNATING-CURRENT ENERGY. By D. T. Canfield. McGraw-Hill Book Company, New York and London, 1940. 210 pages, illustrated, 8½ by 5½ inches, cloth, $2.00. Answers the fundamental questions about devices for the measurement of a-c energy, including explanations of the inductive load adjustment, the retarding force, and the recording mechanism. Meter constants and ratios are discussed. Also presents the development and application of a method of proving the correctness of any proposed metering combination.

THEORY AND PRACTICE OF ELECTRON DIFFRACTION. By G. P. Thomson and W. Cochrane. New York, Macmillan Company, 1939. 334 pages, illustrated, 9 by 6 inches, cloth, $6.00. The discovery of the diffraction of electrons by a crystal has produced developments in two widely different fields. The author covers in this volume both aspects of the discovery, first as the most direct experimental proof of the wave theory of matter, and second as a means of studying the properties of thin surface layers. Both theoretical considerations and practical applications are discussed.

THE TECHNICAL COLLEGE. By W. A. Richardson. New York and London, Oxford University Press, 1939. 495 pages, illustrated, 9 by 6 inches, cloth, $5.00. The principal of a large English technical college surveys the field with a view toward increasing the efficiency of this type of education. He describes the organization and administration of the technical college, the physical equipment, and the types of students to be considered. Relations with industry are discussed, among other problems, and future developments are considered.

HEATING, VENTILATING, AIR CONDITIONING GUIDE, volume 18, 1940. American Society of Heating and Ventilating Engineers, New York, 1940. 1006 pages, illustrated, 9 by 6 inches, cloth, $5.00. Annual summary of the scientific and practical information needed by hesting and ventilating engineers, kept up to date by constant revision. Needed by designers and installers of apparatus, both for domestic and industrial purposes, are considered. A new chapter on unit air-conditioners, cooling units, and attic fans has been added. Also contains a manufacturers' section, which lists apparatus and materials, and the membership list of the Society.

ELECTRIC TRANSPORTATION. By F. R. Thompson. International Textbook Company, Scranton, Pa., 1940. 427 pages, illustrated, 9½ by 6 inches, cloth, $4.00. Presents methods of applying electrical equipment in passenger and freight transportation. Includes selection of general classes of equipment, function of individual groups of parts, commercially practicable ratings and limitations, and operating results. Transportation by city surface cars and busses, subway and elevated systems, and main railways is discussed.

PRACTICAL ELECTRICITY. By T. Croft, revised by G. H. Hall. Fourth edition. McGraw-Hill Book Company, New York, 1940. 701 pages, illustrated, 8½ by 5½ inches, cloth, $3.00. Covers the fundamentals of electricity, with illustrations by practical applications in everyday life. Calls for no special mathematical knowledge and is adapted to home study.

ASTM STANDARDS, INCLUDING TENTATIVE STANDARDS, 1939. Three volumes. Volume 1, Metals, 1308 pages; Volume 2, Nonmetallic Materials, Constructional, 1217 pages; Volume 3, Nonmetallic Materials, General, 1175 pages. American Society for Testing Materials, Philadelphia, Pa., 1939/1940. Illustrated, 9½ by 6 inches, cloth, $8.00, any one part; $15.00, any two parts; $22.00, all three parts. With this issue, a change in the method of publication has been adopted. Hereafter, the standards and tentative standards will be issued collectively, every three years, in the form of this issue. Individual parts may be purchased. Supplements will be issued between editions.

1. TABLE OF THE FIRST TEN POWERS OF THE INTEGERS FROM 1 TO 1,000. Project for the Computation of Mathematical Tables. Works Progress Administration, New York, under the sponsorship of the National Bureau of Standards, Washington, D. C., 1939. 80 pages, tables, 14 by 8½ inches, paper, $0.50. 2. TABLES OF THE EXPONENTIAL FUNCTION $e^x$. Federal Works Agency, Works Project Administration for the City of New York, conducted under the sponsorship of the National Bureau of Standards, 1939. 535 pages, tables, 11 by 8 inches, cloth, $2.00. These publications are the first of a series of mathematical tables. Both are printed in typescript. The second contains tables of the exponential from −2.5000 to 1.0000 at intervals of 0.0001 to 18 decimals; from 1.0000 to 2.5000 at intervals of 0.0001 to 15 decimals; from 2.500 to 5.000 at intervals of 0.001 to 15 decimals; and from 5.00 to 10.00 at intervals of 0.01 to 12 decimals.

WATT-HOUR METERS. By W. C. Wagner. International Textbook Company, Scranton, Pa., 1939. Three sections paged separately, illustrated, 8 by 5 inches, leather, $1.70. Instruction book for metermen on the varieties and applications of watt-hour meters. The characteristics of each type, the construction of various commercial meters, installation and testing, wiring, etc., are described.

ACOUSTICAL SOCIETY OF AMERICA JOURNAL, CUMULATIVE INDEX, volumes 1–10, 1929–1939. Published for the Acoustical Society of America by the American Institute of Physics, Lancaster, Pa., and New York, N. Y., 1939. 131 pages, 10½ by 8 inches, paper, $3.00. Contains author and subject indexes to the first ten volumes of the Journal, as well as to books and papers on acoustical subjects that appeared elsewhere during 1937 and 1938 and were referred to in the Journal.

TELEVISION, THE ELECTRONICS OF IMAGE TRANSMISSION. By V. K. Zworykin and G. A. Morton. John Wiley and Sons, New York, 1940. 646 pages, illustrated, 9 by 6 inches, cloth, $6.00. Most of the literature on television exists only in periodicals. The present work is intended as an integrated, detailed survey of the field. It presents the fundamental physical phenomena involved in television, analyzes the components of the electronic television system based upon the storage principle, and finally describes the television system used in the RCA-NBC project. Brief bibliographies accompany many chapters.

WRITING THE TECHNICAL REPORT. By J. R. Nelson. McGraw-Hill Book Company, New York and London, 1940. 373 pages, diagrams, etc., 9½ by 6 inches, cloth, $2.50. Fundamental considerations that bear on the design and composition of a report are reviewed, and specific directions given for the setup. Several annotated illustrative reports are included. A procedure is outlined for the critical examination of reports, including some typical cases, and suggestions for classroom procedure, made.

AN AIR-CONDITIONING PRIMER, THE A B C OF AIR CONDITIONING. By W. H. Stangle. New York and London, McGraw-Hill Book Company, 1940. 236 pages, illustrated, 9½ by 6 inches, cloth, $2.50. Tells what air conditioning is and what it can do, explains its technical fundamentals and the methods of applying them, and describes types of equipment available. Includes examples of design computations. Some 30 tables of data are appended.

ALTERNATING-CURRENT CIRCUITS. By K. Y. Tang. International Textbook Company, Scranton, Pa., 1940. 438 pages, diagrams, etc., 9½ by 6 inches, cloth, $4.00. Intended as an introductory course in the study of circuit analysis, the material here presented should precede the study of a-c machinery, power, and communication networks. The physical nature of circuit elements and the principles and laws of electric circuits are covered, with emphasis on the effects of the circuit elements on the flow of current and the relations of instantaneous values. Problems.

ELECTRIC DISTRIBUTION FUNDAMENTALS. By F. Sanford. McGraw-Hill Book Company, New York and London, 1940. 242 pages, illustrated, 9½ by 6 inches, cloth, $2.50. Written from a nonengineering viewpoint, this book gives the perspective, development, and economic background of electric distribution as a part of the general system of electric supply. Outlines features of both the utility distribution, and the industrial and inside-wiring branches of service to the outlet. Practical design problems are included, with solutions based on graphical methods rather than on engineering mathematics.

ELECTRICAL METERMEN'S HANDBOOK, Fifth edition, 1940. Edited and published by Edison Electric Institute, New York. 354 pages, illustrated, 10 by 8 inches, cloth, $3.60. Completely revised edition of the "Handbook for Electrical Metermen", the fourth edition of which appeared in 1923. Primarily for the practical meterman and the meter engineer, it contains the basic principles, diagrams of the usual connections for all types of metering, descriptions of laboratory equipment and procedure, full descriptions of all American meters of modern types, and complete tables of constants for all types of meters in current use.

# Institute Activities

## 1940 Summer Convention Program Completed

THE program for the AIEE summer convention, which will be held in Swampscott, Mass., June 24–28, with headquarters in the New Ocean House, provides for a busy and profitable week, yet not without ample opportunities for sports, trips, and social recreation. The business program is comprised of ten technical sessions, a general session, seven technical conferences, the annual meeting, the conference of officers, delegates, and members in two sections, and the conference of Student Branch counselors. As may be seen from the schedule of events, every evening but the last is taken up with some form of entertainment and a special program of events during the days has been arranged by the women's entertainment committee. The summer convention committee has taken advantage of location and hopes to make Swampscott a gathering place for many family groups.

### FREQUENCY-MODULATION DEMONSTRATION

One of the outstanding events of the convention will be the talk on frequency modulation, with demonstrations to be given by W. L. Everitt, The Ohio State University, on Wednesday evening, June 26. In addition to the demonstration of one of the most dramatic effects of frequency modulation, as announced in ELECTRICAL ENGINEERING for May, page 212, Professor Everitt will show a mechanical model which adds two sideband components to a carrier by a chain and gear arrangement. The phase of the components may be changed, and the difference between amplitude and frequency modulation for small deviation ratios shown. By a series of beat notes the large number of sideband components can be shown when the deviation ratio is large—that is, when the frequency swing is large compared with the modulating frequency.

In connection with the broadcast from the 50-kw transmitter at Paxton to show the high quality which can be obtained from a station some 50 miles away, special loudspeakers capable of reproducing the wide range will be used and the program will be selected to bring out this feature. As a high static level probably will prevail in June, the comparison with standard broadcasting should be significant.

### FORMAL BANQUET AND DANCE

The climax to the entertainment program will be the formal banquet and dance, scheduled for 7:00 p.m., Thursday, June 27. The toastmaster will be Professor William H. Timbie of the Massachusetts Institute of Technology and the principal speakers will be Doctor Karl T. Compton, president, Massachusetts Institute of Technology, and Laurence A. Hawkins, executive engineer, research laboratory, General Electric Company. During the banquet Charles L. Clarke, sole surviving AIEE charter member, will be presented to the guests. There will be other special features and the sports prize awards will be presented to the winners.

### INFORMATION ON WEEK-END TOURS

New England affords many opportunities for scenic and historic trips. A representative of the recreational bureau of the New England Council will be at the hotel Thursday afternoon, June 27, to assist in arranging week-end post-convention trips, as desired.

### ADVANCE REGISTRATION

Members who have received an advance registration card should fill in and return the card promptly, if they have not already done so. Hotel reservations should be made directly by writing to the New Ocean House, Swampscott, Mass., or any other hotel preferred.

### TECHNICAL CONFERENCES

Six technical conferences have been scheduled on the following subjects: standards, load swings, introducing modern statistical technique to electrical engineers, principles of nonlinear analysis, test codes, and dielectric measurements in the field. The scope and objectives of several of these conferences were announced in ELECTRICAL ENGINEERING for May, pages 212–13. Such additional information as has become available is announced in the following paragraphs.

*Standards* (*Tuesday, June 25, 2:00 p.m.*). This conference has been arranged to present the work being done by the several coordinating committees, and to encourage greater participation by Institute members in standards activities. The co-ordinating committees are responsible for the development of general principles and fundamental data which are common to the various standards for specific types of apparatus. The growing importance of system coordination, requiring that many different types of apparatus have consistent levels of dielectric strength, overload capacity, short-circuit protection, etc., makes it desirable that the various committees dealing with specific standards reach common agreement on principles.

The discussion at this conference is planned to deal especially with the methods of rating and testing apparatus for intermittent service or short-time loads. The papers by R. E. Hellmund and P. H. McAuley, V. M. Montsinger, and C. G. Veinott, scheduled for presentation at the Tuesday morning session, all deal with various aspects of this subject. It is, therefore, expected that the discussion of these papers at the morning meeting will be carried over into the afternoon conference.

Two informal topics which also deal with this subject will be presented. (1) Proposed Methods of Rating Welding Transformers, by A. U. Welch; and (2) Proposed Methods of Rating Welding Generators, by R. C. Freeman.

Following these informal talks, E. Bennett, chairman, co-ordinating committee 5, will discuss the work on basic theories and units. There also will be a general discussion of a proposed new co-ordinating committee on conduction dealing with the coordination of short-time and intermittent ratings of electrical apparatus and wiring.

*Principles of Nonlinear Analysis* (*Thursday, June 27, 2:00 p.m.*). This is intended to be the first of a series of technical conferences discussing the various methods of analysis of nonlinear problems. As an introductory meeting it will concern itself mainly with the principles of the available methods, surveying their advantages and limitations, and illustrating them with simple applications. In order to guide the general discussion, four basic methods will first be presented informally by prominent authors in the respective fields. Thus, Professor E. G. Keller, University of Texas will introduce the analytical methods with their respective limitations; A. Preisman, RCA Institutes, New York, N. Y., will demonstrate the principles of a graphical approach; Professor J. B. Scarborough, United States Naval Academy, Annapolis, Md., will illustrate numerical methods, and Professor S. H. Caldwell, Massachusetts Institute of Technology, Cambridge, will discuss the use of mechanical machines, to procure solutions of nonlinear problems.

*Test Codes* (*Thursday, June 27, 2:00 p.m.*). The increased variety of performance specifications required of electrical apparatus, and the great severity of requirements in regard to impulse tests, transient currents, short-circuit currents, accelerating torques, and other factors make it desirable more clearly to define test procedures on which performance guarantees are based. In many cases, different types of test may be used for different sizes of apparatus or under different conditions. It is therefore important that both designers and users of apparatus have a better understanding of the testing methods and the degrees of accuracy obtainable with different procedures. For these reasons, the various technical committees in recent years have been engaged in developing a number of different test codes.

### *Future AIEE Meetings*

**Summer Convention**
Swampscott, Mass., June 24–28, 1940

**Pacific Coast Convention**
Los Angeles, Calif., August 27–30, 1940

**Middle Eastern District Meeting**
Cincinnati, Ohio, October 9–11, 1940

**Winter Convention**
Philadelphia, Pa., January 27–31, 1941

At this conference, it is proposed to discuss two new test codes which are now approaching completion, and also to consider revisions in one of the existing codes. The two new test codes to be presented are the test code for single-phase motors and the test code for d-c machines. The third code to be discussed is that for polyphase induction machines.

It has been proposed that material common to several codes, such as methods of measuring temperature, resistance, and dielectric strength, be segregated and placed in a separate code. This proposal has been under consideration by the instruments and measurements committee and will be discussed at this conference.

*Dielectric Measurements in the Field* (*Thursday, June 27, 2:00 p.m.*). This conference is sponsored by a subcommittee of the committee on instruments and measure-

# Technical Program

(Eastern Daylight Saving Time)

**Photo-offset copies of authors' manuscripts, except addresses, may be obtained as soon as available in advance of the convention by writing to the AIEE order department, 33 West 39th Street, New York, N. Y. Only numbered papers will be available in advance-copy form. If ordered by mail, price 10 cents per copy; if purchased at Institute headquarters or at the convention, 5 cents per copy. Mail orders (particularly from out-of-town members) are advisable, inasmuch as an adequate supply of each paper at the meeting cannot be assured. Coupon books in $1 and $5 denominations are available for those who wish to avoid remittance by check or otherwise. Most of the papers ultimately will be published in ELECTRICAL ENGINEERING or the TRANSACTIONS.**

## Tuesday, June 25

### 9:00 a.m. Power Transmission

40-107. SHIELDING OF TRANSMISSION LINES. **C. F. Wagner, G. D. McCann, and G. L. MacLane, Jr.,** Westinghouse Electric and Manufacturing Company

40-105. ABNORMAL VOLTAGE CONDITIONS IN THREE-PHASE SYSTEMS PRODUCED BY SINGLE-PHASE SWITCHING. **Edith Clarke, H. A. Peterson, and P. H. Light,** General Electric Company

40-106. ARCING FAULTS IN POWER SYSTEMS. **C. Concordia and H. A. Peterson,** General Electric Company

### 9:00 a.m. Standards

40-94. RATING OF POTENTIAL DEVICES AND SUGGESTED STANDARDS. **J. E. Clem,** General Electric Company, **and P. O. Langguth,** Westinghouse Electric and Manufacturing Company

40-95. SOME PROBLEMS IN THE STANDARDIZATION OF TEMPERATURE RATINGS OF FRACTIONAL HORSEPOWER MOTORS. **C. G. Veinott,** Westinghouse Electric and Manufacturing Company

40-93. A STUDY OF SHORT-TIME RATINGS AND THEIR APPLICATION TO INTERMITTENT DUTY CYCLES. **R. E. Hellmund and P. H. McAuley,** Westinghouse Electric and Manufacturing Company

40-96. EFFECT OF LOAD FACTOR ON OPERATION OF POWER TRANSFORMERS BY TEMPERATURE. **V. M. Montsinger,** General Electric Company

40-92. REFERENCE VALUES FOR TEMPERATURE, PRESSURE, AND HUMIDITY. **P. L. Bellaschi and P. H. McAuley,** Westinghouse Electric and Manufacturing Company

### 9:00 a.m. Basic Sciences

40-108. TRANSIENT ANALYSIS OF COMPLETELY TRANSPOSED MULTICONDUCTOR TRANSMISSION LINES. **L. A. Pipes,** Harvard University

40-109. LINEAR TRANSFORMATIONS IN THREE-PHASE CIRCUITS. **L. A. Pipes,** Harvard University

40-110. SOME CHARACTERISTICS AND APPLICATIONS OF NEGATIVE GLOW LAMPS. **H. M. Ferree,** General Electric Company

### 9:00 a.m. Electronics

40-111. A DECADE OF PROGRESS IN ELECTRONIC MEANS OF COMMUNICATION. Report of Subcommittee on Electronics, prepared by **S. B. Ingram,** Bell Telephone Laboratories, Inc.

40-112. A DECADE OF PROGRESS IN THE USE OF ELECTRONIC TUBES IN OTHER THAN THE COMMUNICATION FIELD. Report of Subcommittee on Electronics, prepared by **W. C. White,** General Electric Company

40-113. MEASUREMENTS AT RADIO FREQUENCIES. **H. P. Meahl, P. C. Michel, M. W. Scheldorf,** and **T. M. Dickinson,** General Electric Company

## Wednesday, June 26

### 9:00 a.m. Communication

40-116. FREQUENCY MODULATION. **W. L. Everitt,** The Ohio State University

40-117. AIRCRAFT STORM-STATIC RADIO INTERFERENCE. **E. C. Starr,** Oregon State College

40-118. HIGH-VOLTAGE DIRECT-CURRENT POINT DISCHARGES. **E. C. Starr,** Oregon State College

40-119. A WIDE-BAND SQUARE-WAVE GENERATOR. **E. H. B. Bartelink,** General Electric Company

### 9:00 a.m. Testing of Insulation and Cables

40-81. LOW-VOLTAGE D-C MEASUREMENTS ON ELECTRICAL INSULATING OILS. **J. L. Oncley and W. C. Hollibaugh,** Massachusetts Institute of Technology

40-82. RAPID RECORDING A-C BRIDGE. **W. Mikelson and H. W. Bousman,** General Electric Company

40-84. A METHOD FOR DETECTING THE IONIZATION POINT ON ELECTRICAL APPARATUS. **G. E. Quinn,** Consolidated Edison Company of New York, Inc.

40-121. THE TYPE CB IMPREGNATED-PAPER CABLE. **S. J. Rosch,** Anaconda Wire and Cable Company

40-104. THE DIELECTRIC STRENGTH AND LIFE OF IMPREGNATED PAPER INSULATION—II: The Influence of the Thickness of the Paper. **J. B. Whitehead,** The Johns Hopkins University

### 9:00 a.m. Transportation

40-122. MODERN RAIL TRANSPORT. **A. M. Wright,** The Central Railroad Company of New Jersey

40-123. THE APPLICATION OF ELECTRICITY FOR THE AUXILIARIES OF RAILROAD TRAINS. **J. E. Gardner,** Chicago, Burlington, and Quincy Railroad Company

40-124. INVESTIGATION OF STARTING REQUIREMENTS FOR ALCO 660-HORSEPOWER DIESEL ENGINE. **J. C. Davidson and R. Lamborn,** General Electric Company

## Thursday, June 27

### 10:00 a.m. General Session

## Friday, June 28

### 9:00 a.m. Protective Devices

40-103. A HIGH-SPEED DIFFERENTIAL RELAY FOR GENERATOR PROTECTION. **W. K. Sonnemann,** Westinghouse Electric and Manufacturing Company

40-87. HARMONIC-CURRENT-RESTRAINED RELAYS FOR TRANSFORMER DIFFERENTIAL PROTECTION. **C. D. Hayward,** General Electric Company

40-85. A HIGH-POWER OILLESS CIRCUIT INTERRUPTER USING WATER. **W. M. Leeds,** Westinghouse Electric and Manufacturing Company

40-125. MEDIUM-CAPACITY AIR-BLAST CIRCUIT BREAKERS FOR METAL-CLAD SWITCHGEAR. **R. M. Bennett and B. W. Wyman,** General Electric Company

40-86. DIELECTRIC STRENGTH OF WATER IN RELATION TO USE IN CIRCUIT INTERRUPTERS. **Joseph Slepian, C. L. Denault,** and **A. P. Strom,** Westinghouse Electric and Manufacturing Company

### 9:00 a.m. Instruments and Measurements

40-88. AN IMPROVED TYPE OF DIRECT-CURRENT WATTMETER OF THE SHUNTED TYPE. **Paul MacGahan,** Westinghouse Electric and Manufacturing Company

40-89. COMPUTATION OF ACCURACY OF CURRENT TRANSFORMERS. **A. T. Sinks,** General Electric Company

40-90. NEW INSTRUMENTS FOR RECORDING LIGHTNING CURRENTS. **C. F. Wagner and G. D. McCann,** Westinghouse Electric and Manufacturing Company

40-91. THE OUTPUT AND OPTIMUM DESIGN OF PERMANENT MAGNETS SUBJECTED TO DEMAGNETIZING FORCES. **A. J. Hornfeck,** Bailey Meter Company, **and R. F. Edgar,** General Electric Company

40-97. A NEW HIGH-SPEED THERMAL WATTMETER. **John H. Miller,** Weston Electrical Instrument Corporation

### 9:00 a.m. Electrical Machinery

40-98. AN EXTENSION OF THE METHOD OF SYMMETRICAL COMPONENTS USING LADDER NETWORKS. **W. V. Lyon,** Massachusetts Institute of Technology

40-99. EFFECTIVE RESISTANCE TO ALTERNATING CURRENTS OF MULTILAYERED WINDINGS. **Edward Bennett,** University of Wisconsin, **and Sidney C. Larson,** General Electric X-Ray Corporation

40-100. TRANSIENT STARTING TORQUES IN INDUCTION MOTORS. **A. M. Wahl and L. A. Kilgore,** Westinghouse Electric and Manufacturing Company

40-101. DEAD POINTS IN SQUIRREL-CAGE MOTORS. **Quentin Graham,** Westinghouse Electric and Manufacturing Company

40-102. PERFORMANCE OF TRAVELING WAVES IN COILS AND WINDINGS. **R. Rudenberg,** Harvard University

ments. It will cover the various types of testing equipment and test methods used to determine the quality of insulation of electrical apparatus in service. A number of prepared discussions will be presented, and it is hoped that additional discussion will be contributed by any who desire to attend. In this way it is believed that the subject will be clarified and the publication of future papers will be encouraged.

A schedule of convention events was published in the May issue, page 212.

### COLONEL ROBERT S. HENRY TO ADDRESS JOINT GENERAL SESSION

Feature of the general session, which is being held jointly with the American Engineering Council, Thursday, June 27, at 10 a.m., will be an address on "Transportation as a Social Problem", by Colonel Robert Selph Henry, assistant to the president, Association of American Railroads.

Widely known as a colorful and highly qualified speaker, Colonel Henry has been intimately associated with American railroading since 1921. He was born in Clifton, Tenn., in 1889, and educated in Nashville, Tenn., receiving the degrees of bachelor of laws (1910) and bachelor of arts (1911) from Vanderbilt University. He was admitted to the Tennessee bar in 1911, and after working as a newspaper reporter and serving as private secretary to the governor of Tennessee, he began the practice of law in Nashville in 1915.

Colonel Henry is the author of several books on trains and rail transportation: "Trains", "On the Railroad", and "Portraits of the Iron Horse". He has also published two books on Confederate history, a subject in which he became interested as a hobby and on which he now is regarded as an authority.

## 1940 Lamme Medal Nominations Due December 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the AIEE Lamme Medal, to be awarded early in 1940, may be submitted by any member in accordance with section 1 of article VI of the bylaws of the Lamme Medal committee, as quoted in the following:

> The committee shall cause to be published in one or more issues of ELECTRICAL ENGINEERING, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by December 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least three engineers, of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specific information should be given regarding his individual contributions. Names of endorsers should be given as specified in the foregoing quotation.

# Section and Branch Activities

## Annual Report for 1939–40

THE following constitutes the annual report on Institute Section and Branch activities for the fiscal year which ended April 30, 1940. Similar information for three preceding fiscal years appeared in ELECTRICAL ENGINEERING for June 1939, pages 268–71; June 1938, pages 263–6; June 1937, pages 762–5.

Present members of the Sections committee and the committee on Student Branches, which supervise the two important divisions of Institute activities covered by this report, are:

Sections—H. H. Race, *chairman*, M. S. Coover, C. A. Faust, O. W. Holden, E. T. Mahood, I. M. Stein, J. M. Thomson, W. H. Timbie, and *ex-officio*, the chairmen of all Sections of the Institute.

Student Branches—R. W. Sorensen, *chairman*, C. T. Almquist, S. S. Attwood, H. W. Bibber, W. C. DuVall, E. A. Loew, C. W. Ricker, Charles P. Scott, E. M. Strong, and *ex-officio*, all Student Branch counselors.

### SECTION ACTIVITIES

Three new Sections were organized: Charleston (W. Va.), El Paso, and South Carolina. On account of their extensive territories, the names of two Sections were changed: Baltimore to "Maryland" and Dallas to "North Texas". The territory of the North Texas Section was extended to include some unassigned counties to the north and northwest. The nine unassigned counties in Maine were assigned to the Lynn Section, which now has the entire state.

All Sections reported activity during the year, and the total number of meetings reported was 701, as compared with 635 for the preceding year. This was the sixth consecutive fiscal year in which the number was larger than for any preceding year. Nine Sections held more than 15 meetings each, 7 held from 12 to 15, 36 held from 8 to 11, 10 held from 4 to 7, and only 8, including 3 recently organized, held fewer than 4 meetings each.

Fifteen Sections reported meetings by a total of 30 technical groups or other subdivisions, with a total of 124 meetings of these types, in addition to 131 regular Section meetings.

The number of members in the United States outside of Section territories was reduced in 1937, by revision of many of the territories, to about 200. The formation of new Sections and some further revisions in territories have reduced this number to 101 as of February 29, 1940. These are located in 50 cities and towns in 11 states, with the maximum numbers of 11 in one city, and 23 in one state.

In October 1939, the Sections committee issued a printed pamphlet entitled "Section Activities", containing in condensed form information on the aims and activities of the Sections collected during the preceding three years, and intended to assist Section officers in their efforts to become acquainted with the types of activities which have been found to be most fruitful. Under the joint direction of the Sections committee and the committee on Student Branches, copy for a second edition of the pamphlet "The Electrical Engineer" was prepared. Distribution of printed copies was begun in March.

The Sections committee recommended to the Sections that each appoint committees on (*a*) legislation, (*b*) economic and social affairs, and (*c*) vocational guidance.

During the past year, the Sections committee has developed a comprehensive plan for the preparation by one of its members of news items on outstanding Section activities for publication in ELECTRICAL ENGINEERING, and many have appeared.

The Sections committee is making a comprehensive study of all phases of Section activities through a detailed questionnaire sent out in two parts in March and April.

In addition to officers of the Institute, E. H. Armstrong, P. A. Borden, F. A. Cowan, W. A. Gluesing, R. J. Kryter, Everett S. Lee, A. C. Monteith, J. O. Perrine, M. E. Strieby, C. F. Wagner, and W. E. Wickenden each gave addresses at meetings of 3 or more Sections, the larger numbers being 20 for Mr. Wagner, and 8 for Doctor Perrine.

The interest of the Sections in increasing the participation by the younger members in their activities has advanced rapidly, as shown by the outstanding success of the technical group discussion plan, the appointment of committees on younger engineers, and the growing practice of including some of the younger men among the regular Section officers and committees.

The first joint meeting of the Chicago Section and the Student Branches at Northwestern University and Armour and Lewis Institutes was held at Northwestern University in March. The Section sponsored a paper-writing contest for students, with arrangements that each of the three Branches should conduct a contest and submit its two best papers to the judges appointed by the Section, and that the two best papers selected by them should be presented in final competition at the joint meeting. Prizes of $20 and $10 were awarded. The student papers were followed by an address on "The Engineers' Job", by Alex D. Bailey, chief operating engineer, Commonwealth Edison Company. The Section hopes to have such a meeting annually.

Some of the Sections which have recently established committees on activities for the younger members are: Chicago, Cincinnati, Maryland, and Washington. The Maryland Section's discussion committee, composed of younger men, promotes interest among the younger members, and arranges for a brief talk, preferably by a younger member, preceding each main lecture. The Washington Section began holding junior technical sessions.

The Maryland Section held its first paper-writing contest for students, with an engraved sterling-silver goblet and an engraved sterling-silver key chain as prizes. The two winning papers were presented at a joint meeting with the Johns Hopkins University Branch. The Section has also begun holding weekly luncheon meetings with attendance from 12 to 20.

The Los Angeles Section followed its custom of many years standing by celebrating its past chairmens' night. All past

chairmen were invited to the dinner meeting as guests of the Section, and of the 25 living 21 attended. One of them was appointed toastmaster, and each was introduced and given an opportunity to speak.

The Lynn Section held a question-and-answer meeting at which certain electrical engineers answered questions on electrical subjects which they had not seen in advance. Prizes were offered for any such questions which they were unable to answer.

In the Lynn Section's technical-paper competition for its members under 35 years of age, 20 papers were submitted, 8 were presented at its local convention on March 26, and prizes of $15, $10, and $5 were awarded.

The Madison Section authorized the formation of a Rock River Valley subsection with headquarters in Rockford, Ill., and also including members in Beloit, Wis., and Freeport, Ill.

The Michigan Section has been conducting for several years round-table discussions on specialized technical subjects. The freedom of discussion and increasing interest in these have been noticeable during the past year.

The Michigan Section continued its cooperation with the Engineering Society of Detroit in the holding of an annual meeting for high-school seniors interested in engineering. The meeting held in December 1939 was attended by more than 300 seniors, and was considered highly successful.

The Milwaukee Section distributed to its members on March 6 a questionnaire regarding the desirability of organizing technical discussion groups, requesting information as to what divisions of electrical engineering are of greatest interest.

The power group of the New York Section has continued its practices of holding a prize paper contest and providing several educational courses on subjects of keen interest to many members, and the communication group provided a series of six lectures on modern methods for communication measurements. It has been holding occasional

**Table I. Section Meetings Held During Year Ending April 30, 1940**

| Section | AIEE Members August 1938 | AIEE Members August 1939 | Meetings During Year Number | Meetings During Year Average Attendance | Average Attendance as Per Cent of Membership, August 1939 |
|---|---|---|---|---|---|
| Akron | 76 | 75 | 8 | 65 | 87 |
| Alabama | 39 | 31 | 3 | 18 | 58 |
| Boston | 411 | 414 | 9 | 225 | 54 |
| Central Indiana | 123 | 126 | 6 | 119 | 94 |
| Charleston, W. Va.* | | 1 | | 22 | |
| Chicago | 697 | 733 | 5 | 294 | 40 |
| Industrial group | | | 3 | 89 | |
| Power group | | | 4 | 108 | |
| Communication group | | | 4 | 433 | |
| Cincinnati | 182 | 180 | 10 | 219 | 122 |
| Cleveland | 300 | 298 | 10 | 225 | 75 |
| Technical group | | | 6 | 64 | |
| Columbus | 87 | 95 | 7 | 43 | 45 |
| Connecticut | 267 | 265 | 10 | 95 | 36 |
| Denver | 168 | 182 | 8 | 73 | 40 |
| East Tennessee | 102 | 118 | 11 | 98 | 83 |
| El Paso** | | 2 | | 25 | |
| Erie | 67 | 65 | 9 | 123 | 189 |
| Florida | 68 | 73 | 3 | 121 | 166 |
| Fort Wayne | 88 | 98 | 11 | 168 | 171 |
| Georgia | 97 | 104 | 12 | 115 | 111 |
| Houston | 116 | 139 | 8 | 89 | 64 |
| Iowa | 50 | 67 | 7 | 26 | 39 |
| Ithaca | 47 | 51 | 10 | 55 | 108 |
| Kansas City | 124 | 125 | 9 | 108 | 86 |
| Lehigh Valley | 193 | 191 | 7 | 91 | 48 |
| Los Angeles | 486 | 483 | 10 | 175 | 36 |
| Louisville | 50 | 56 | 7 | 92 | 164 |
| Lynn | 130 | 145 | 4 | 800 | 552 |
| Inspection trips | | | 4 | 78 | |
| Technical lectures | | | 5 | 355 | |
| Local conventions | | | 2 | 175 | |
| Madison | 64 | 65 | 6 | 61 | 94 |
| Rock River Valley Subsection | | | 3 | 42 | |
| Mansfield | | 64 | 8 | 223 | 348 |
| Maryland | 201 | 224 | 11 | 131 | 58 |
| Memphis | 53 | 61 | 11 | 60 | 98 |
| Mexico | 66 | 56 | 1 | 27 | 48 |
| Michigan | 342 | 358 | 9 | 189 | 53 |
| Round table discussions | | | 4 | 19 | |
| Milwaukee | 297 | 270 | 13 | 170 | 63 |
| Minnesota | 83 | 89 | 5 | 73 | 82 |
| Power group | | | 1 | 52 | |
| Montana | 39 | 39 | 2 | | |
| Muscle Shoals | 40 | 46 | 8 | 22 | 48 |
| Nebraska | 58 | 56 | 6 | 237 | 423 |
| New Orleans | 78 | 97 | 7 | 79 | 81 |
| New York | 3,346 | 3,355 | 5 | 380 | 11 |
| Communication group | | | 5 | 189 | |
| Basic science group | | | 3 | 160 | |
| Power group | | | 11 | 143 | |
| Illumination group | | | 3 | 517 | |
| Transportation group | | | 2 | 150 | |
| Niagara Frontier | 205 | 201 | 9 | 219 | 109 |
| North Carolina | 78 | 85 | 2 | 88 | 104 |
| North Texas | 114 | 140 | 10 | 112 | 80 |
| Oklahoma City | 106 | 120 | 11 | 128 | 107 |
| Philadelphia | 580 | 610 | 9 | 158 | 26 |
| Power systems group | | | 3 | | |
| Industrial practice group | | | 3 | | |
| Communication group | | | 4 | | |
| Pittsburgh | 503 | 517 | 8 | 236 | 46 |
| Pittsfield | 167 | 178 | 6 | 1,013 | 569 |
| Technical meetings | | | 5 | 217 | |
| Colloquium meetings | | | 5 | 21 | |
| Portland | 125 | 151 | 9 | 91 | 60 |
| Communication committee | | | 5 | 41 | |
| Transmission and distribution committee | | | 6 | 99 | |
| Providence | 95 | 91 | 8 | 204 | 224 |
| Rochester | 94 | 95 | 10 | 161 | 169 |
| Communication group | | | 1 | 76 | |
| Luncheon meetings | | | 4 | 25 | |
| St. Louis | 247 | 268 | 10 | 109 | 41 |
| San Antonio | 37 | 43 | 8 | 52 | 121 |
| San Diego | | 30 | 8 | 84 | 280 |
| San Francisco | 457 | 486 | 10 | 146 | 30 |
| Technical meetings | | | 7 | 79 | |
| Saskatchewan | 25 | 21 | 11 | 35 | 167 |
| Schenectady | 428 | 403 | 8 | 213 | 53 |
| Technical discussion meetings | | | 4 | 119 | |
| Open forum series | | | 6 | 20 | |
| Seattle | 156 | 153 | 10 | 106 | 69 |
| Technical meetings | | | 4 | 56 | |
| Sharon | 80 | 86 | 10 | 96 | 112 |
| South Carolina† | | | 2 | 37 | |
| Spokane | 62 | 62 | 8 | 61 | 98 |
| Springfield | 57 | 60 | 8 | 160 | 267 |
| Syracuse | 73 | 71 | 25 | 146 | 206 |
| Toledo | 78 | 78 | 10 | 85 | 109 |
| Toronto | 348 | 338 | 8 | 169 | 50 |
| Discussion group | | | 6 | 82 | |
| Tulsa | 88 | 107 | 9 | 104 | 97 |
| Urbana | 65 | 77 | 8 | 187 | 243 |
| Utah | 56 | 76 | 7 | 47 | 62 |
| Vancouver | 98 | 107 | 10 | 54 | 50 |
| Virginia | 92 | 94 | 4 | 67 | 71 |
| Washington | 288 | 332 | 11 | 133 | 40 |
| Technical sessions | | | 9 | 120 | |
| Junior technical sessions | | | 2 | 55 | |
| Wichita | 33 | 46 | 11 | 41 | 89 |
| Worcester | 69 | 58 | 9 | 91 | 157 |
| Total | 70 | 13,539 | 14,078 | | |

Total number of meetings ..... 701
Total attendance ..... 91,949

*Organized April 9, 1940. **Organized March 7, 1940. †Organized March 2, 1940.

**Table II. Section Meetings Held During Last Three Fiscal Years**

| | Fiscal Year Ending April 30 1938 | 1939 | 1940 |
|---|---|---|---|
| Number of Sections | 65 | 67 | 70 |
| Number of meetings held | 624 | 635 | 701 |
| Average number of meetings | 9.6 | 9.5 | 10.0 |
| Total attendance | 110,148 | 85,692 | 91,949 |
| Average attendance per meeting | 177 | 135 | 131 |

**Table III. Prizes Awarded by Sections**

| Section | Number of Papers Presented | Awards |
|---|---|---|
| Central Indiana | 3 | $5, $3, $2 |
| Chicago | 3 | $20, $10 |
| Cincinnati | 6 | $10, $5 |
| Houston | 4 | $15, $10, $5 |
| Iowa | 6 | Two Standard Handbooks |
| Kansas City | 4 | $15, $10, $5, pocket slide rule |
| Los Angeles | 4 | $15 |
| Maryland | 3 | Silver goblet, two silver key chains |
| Minnesota | 4 | $15, $10, $5, $5 |
| New Orleans | 3 | Two Associate membership prizes |
| New York | 7 | $25, $10 |
| Pittsfield* | 8 | $15, $10 |
| Portland | 3 | One year Associate dues |
| St. Louis | 6 | $15, $10, $5 |
| Schenectady* | 6 | $15, $10 |
| Toronto | 4 | Two prizes |
| Urbana | 4 | $5, $3, $2 |
| Utah | 3 | One year Associate dues |
| Worcester | 5 | $10, $5 |

* Two meetings in competition between Sections.

## Table IV. Branch Meetings Held During Year Ending April 30, 1940

| Branch | Meetings During Year: Number | Average Attendance | Approximate Number of Talks by Students |
|---|---|---|---|
| Akron, University of | 10 | 24 | 1 |
| Alabama Polytechnic Institute | 14 | 41 | 5 |
| Alabama, University of | 11 | 19 | 9 |
| Alberta, University of* | 7 | 23 | 5 |
| Arizona, University of | 27 | 12 | 22 |
| Arkansas, University of | 11 | 21 | 3 |
| Armour Institute of Technology | 8 | 52 | 2 |
| British Columbia, University of | 10 | 19 | 16 |
| Brooklyn, Polytechnic Institute of | | | |
| Day division | 1 | 55 | |
| Evening division | 7 | 22 | 4 |
| Brown University | 4 | 14 | |
| Bucknell University | 13 | 21 | 1 |
| California Institute of Technology | 17 | 31 | 4 |
| California, University of | 27 | 35 | 15 |
| Carnegie Institute of Technology | 29 | 56 | 23 |
| Case School of Applied Science | 24 | 51 | 23 |
| Catholic University of America | 2 | 12 | |
| Cincinnati, University of | 10 | 158 | 7 |
| Clarkson College of Technology | 9 | 40 | |
| Clemson Agricultural College | | | |
| Colorado State Agricultural College | 6 | 105 | 3 |
| Colorado, University of | 8 | 60 | 5 |
| Columbia University | 1 | 23 | |
| Cooper Union | | | |
| Day division | 8 | 20 | 2 |
| Evening division | 7 | 19 | 5 |
| Cornell University | 5 | 60 | |
| Denver, University of | 6 | 53 | |
| Detroit, University of | 9 | 51 | |
| Drexel Institute | 13 | 24 | 4 |
| Duke University | 12 | 20 | 1 |
| Florida, University of | 6 | 29 | 1 |
| George Washington University | 9 | 32 | 2 |
| Georgia School of Technology | 9 | 53 | |
| Harvard University | 3 | 84 | |
| Idaho, University of | 17 | 39 | 4 |
| Illinois, University of | 10 | 630 | 4 |
| Iowa State College | 5 | 102 | 2 |
| Iowa, University of | 12 | 34 | 9 |
| Johns Hopkins University | 18 | 23 | 14 |
| Kansas State College | 9 | 130 | 13 |
| Kansas, University of | 9 | 38 | 2 |
| Kentucky, University of | 24 | 58 | 2 |
| Lafayette College | 12 | 12 | 6 |
| Lehigh University | 5 | 71 | 3 |
| Lewis Institute | 15 | 26 | |
| Louisiana State University | 16 | 21 | 4 |
| Louisville, University of | 8 | 20 | 4 |
| Maine, University of | 11 | 21 | 3 |
| Marquette University | 6 | 20 | |
| Maryland, University of | 7 | 26 | 4 |
| Massachusetts Institute of Technology | 10 | 67 | |
| Michigan College of Mining and Technology | 9 | 578 | |
| Michigan State College | 13 | 27 | |
| Michigan, University of | 10 | 52 | |
| Milwaukee School of Engineering | 9 | 48 | |
| Minnesota, University of | 11 | 70 | 4 |
| Mississippi State College | 3 | 41 | |
| Missouri School of Mines and Metallurgy | 10 | 32 | 7 |
| Missouri, University of | 7 | 40 | 3 |
| Montana State College | 35 | 49 | 129 |
| Nebraska, University of | 17 | 116 | 6 |
| Nevada, University of | 13 | 24 | 3 |
| Newark College of Engineering | 10 | 35 | 7 |
| New Hampshire, University of | 18 | 22 | 9 |
| New Mexico State College | 14 | 19 | 7 |
| New Mexico, University of | 9 | 14 | 10 |
| New York, College of the City of | | | |
| Day division | 30 | 51 | 4 |
| Evening division | | | |
| New York University | | | |
| Day division | 5 | 28 | |
| Evening division | 6 | 20 | 1 |
| North Carolina State College | 15 | 50 | 2 |
| North Dakota State College | 6 | 18 | 2 |
| North Dakota, University of | 11 | 14 | 4 |
| Northeastern University | 20 | 55 | 7 |
| Northwestern University | 5 | 42 | |
| Notre Dame, University of | 11 | 35 | 3 |
| Ohio Northern University | 15 | 37 | 7 |
| Ohio State University | 12 | 38 | 9 |
| Ohio University | 7 | 23 | |
| Oklahoma A. & M. College | 12 | 228 | 7 |
| Oklahoma, University of | 12 | 72 | 5 |
| Oregon State College | 13 | 61 | 9 |
| Pennsylvania State College | 9 | 43 | |
| Pennsylvania, University of | 3 | 24 | |
| Pittsburgh, University of | 25 | 100 | 18 |
| Puerto Rico, University of | 6 | | 2 |
| Pratt Institute | 22 | 45 | 5 |
| Princeton University | 5 | 14 | 4 |
| Purdue University | 15 | 69 | |
| Rensselaer Polytechnic Institute | 7 | 166 | 12 |
| Rhode Island State College | 18 | 24 | |
| Rice Institute | 12 | 16 | 2 |
| Rose Polytechnic Institute | 4 | 71 | 2 |
| Rutgers University | 7 | 34 | 2 |
| Santa Clara, University of | 14 | 11 | 11 |
| South Carolina, University of | 4 | 24 | |
| South Dakota State College | 12 | 21 | 4 |
| South Dakota State School of Mines | 10 | 19 | |
| Southern California, University of | 13 | 45 | 11 |
| Southern Methodist University | 3 | 16 | 1 |
| Stanford University | 8 | 23 | |
| Stevens Institute of Technology | | | |
| Swarthmore College | 9 | 24 | 2 |
| Syracuse University | 19 | 22 | 19 |
| Tennessee, University of | 10 | 28 | |
| Texas A. & M. College | 10 | 44 | 4 |
| Texas Technological College | 15 | 24 | 4 |
| Texas, University of | 7 | 72 | 6 |
| Tufts College | 6 | 53 | 6 |
| Tulane University | 9 | 25 | 3 |
| Union College | 3 | 27 | |
| Utah, University of | 5 | 30 | 3 |
| Vermont, University of | 8 | 25 | 5 |
| Villanova College | 15 | 15 | 4 |
| Virginia Military Institute | 13 | 45 | 6 |
| Virginia Polytechnic Institute | 20 | 66 | 12 |
| Virginia, University of | 9 | 21 | 3 |
| Washington, State College of | 19 | 46 | 7 |
| Washington, University of | 11 | 61 | 8 |
| Washington University | 11 | 23 | |
| West Virginia University | 19 | 25 | 102 |
| Wisconsin, University of | 7 | 54 | 5 |
| Worcester Polytechnic Institute | 7 | 61 | 9 |
| Wyoming, University of | 9 | 12 | 3 |
| Yale University | 3 | 27 | |
| Total | 121 | | 767 |
| Total number of meetings | | | 1,346 |
| Total attendance | | | 64,972 |

* Authorized by board of directors, May 26, 1939.

round-table meetings to provide opportunities for informal discussions among members in similar fields of work.

The Oklahoma City Section devoted one of its meetings to the presentation of papers by four of its members, with a time allotment of about 25 minutes each. The Tulsa Section had a similar type of meeting with each of four speakers limited to about 15 minutes.

The Philadelphia Section has established three discussion groups: communication, industrial practice, and power systems, which are holding a total of 10 meetings per year with excellent attendance. Plans are under way for the formation of a discussion group on instruments and measurements. During the past year, informal weekly luncheons have been held with a weekly drawing for a free lunch; average attendance 22.

The Schenectady Section and three other organizations sponsored a technical discussion series, and an open forum series of six meetings with addresses by the heads of six divisions of the city government.

Tables I, II, and III contain detailed information on Section activities. Table VI presents a comprehensive record of cooperation between Sections and Branches, with 26 Sections and 39 Branches participating, as compared with 20 Sections and 30 Branches for the preceding year.

## Table V. Branch Meetings Held During Last Three Fiscal Years

| | Fiscal Year Ending April 30: 1938 | 1939 | 1940 |
|---|---|---|---|
| Number of Branches | 120 | 120 | 121 |
| Number of meetings held | 1,334 | 1,190 | 1,346 |
| Average number of meetings | 11.1 | 9.9 | 11.1 |
| Total attendance | 60,446 | 53,380 | 64,972 |
| Average attendance per meeting | 45.3 | 44.8 | 48.3 |
| Number of student talks | 897 | 725 | 767 |

### STUDENT ACTIVITIES

The organization of the University of Alberta Branch in May 1939 brought the total number to 121.

Only two Branches failed to report any activity during the year. The total number of meetings was 1,346, as compared with 1,190 for the preceding year, 1,334 for 1937–38, and 1,363 for 1936–37. Twenty-one Branches held more than 15 meetings each, 24 held from 12 to 15, 40 held from 8 to 11, 26 held from 4 to 7, and only 10 held fewer than 4 meetings.

The total number of talks by students was 767, a slight increase over the 725 for the preceding year, but far below the totals for some previous years. This fundamentally important phase of Branch work offers the greatest opportunity for improvement in the activities.

Of 1,624 Enrolled Students whose terms, according to Institute records, were expected to expire on April 30, 911 or about 56 per cent applied for admission as Associates. The corresponding records for the preceding year were 1,564, 849, and 54 per cent.

The committee on Student Branches

**Table VI. Section or Joint Section and Branch Meetings With Active Student Participation**

| Sections | Schools | Date | Student Talks | Attendance |
|---|---|---|---|---|
| San Antonio | University of Texas | 5/1/39 | 4 | 31 |
| New Orleans | Louisiana State University<br>Tulane University | 5/5/39 | 3 | 110 |
| North Carolina | North Carolina State College | 5/5/39 | 1 | 74 |
| Los Angeles | California Institute of Technology<br>University of Southern California | 5/9/39 | 4 | 99 |
| Cincinnati | University of Cincinnati | 5/11/39 | 6 | 110 |
| Oklahoma City | University of Oklahoma | 5/18/39 | 2 | 146 |
| St. Louis | Missouri School of Mines and Metallurgy<br>University of Missouri<br>Washington University | 5/19/39 | 6 | 100 |
| Portland | Oregon State College | 5/20/39 | 3 | 78 |
| Utah | University of Utah | 5/22/39 | 3 | 36 |
| Madison | University of Wisconsin | 5/23/39 | 4 | 50 |
| Worcester | Worcester Polytechnic Institute | 5/24/39 | 5 | 80 |
| Toronto | University of Toronto | 12/8/39 | 4 | 67 |
| San Antonio | University of Texas | 12/14/39 | 1 | 75 |
| Pittsburgh | Carnegie Institute of Technology<br>Pennsylvania State College<br>University of Pittsburgh<br>West Virginia University | 1/9/40 | 4 | 266 |
| Vancouver | University of British Columbia | 2/26/40 | 4 | 51 |
| Kansas City | University of Kansas | 3/7/40 | 4 | 170 |
| Akron | University of Akron | 3/12/40 | 1 | 76 |
| Houston | Rice Institute<br>Texas A. & M. College | 3/15/40 | 4 | 80 |
| North Texas | Southern Methodist University | 3/25/30 | 3 | 68 |
| Chicago | Armour Institute of Technology<br>Lewis Institute<br>Northwestern University | 3/28/40 | 2 | 125 |
| Urbana | University of Illinois | 4/4/40 | 4 | 35 |
| Central Indiana | University of Illinois<br>Purdue University<br>Rose Polytechnic Institute | 4/6/40 | 3 | 187 |
| Los Angeles | California Institute of Technology<br>University of Southern California | 4/9/40 | 5 | 300 |
| New Orleans | Louisiana State University<br>Tulane University | 4/15/40 | 2 | |
| Minnesota | University of Minnesota | 4/22/40 | 4 | 100 |
| El Paso | New Mexico State College | 4/25/40 | 2 | 19 |
| Iowa | Iowa State College<br>University of Iowa | 4/25/40 | 6 | 62 |
| New York and District 3 | College of the City of New York<br>Columbia University<br>Cooper Union<br>Newark College of Engineering<br>New York University<br>Polytechnic Institute of Brooklyn<br>Pratt Institute<br>Rutgers University<br>Stevens Institute of Technology | 4/25/40 | 7 | 400 |
| Spokane | University of Idaho<br>State College of Washington | 4/26/40 | 2 | 119 |
| Maryland | Johns Hopkins University | 4/29/40 | 3 | 90 |
| Totals—26 Sections, 39 Branches | | | 106 | 3,204 |

**Table VII. Conferences on Student Activities**

| District | Location | Date |
|---|---|---|
| 1 | Springfield, Mass. (North Eastern District meeting) | 5/3–5/39 |
| 8 and 9, University of British Columbia | San Francisco, Calif. (Pacific Coast convention) | 6/26–30/39 |
| 5 | Minneapolis, Minn. (Great Lakes District meeting) | 9/18/39 |
| 2 | Scranton, Pa. (Middle Eastern District meeting) | 10/11–13/39 |
| 4 | Mississippi State College, State College | 4/13/40 |
| 6 | University of North Dakota, Grand Forks | 4/19–20/40 |
| 7 | Texas Technological College, Lubbock | 4/19–20/40 |

**Table VIII. Student Conventions**

| Sponsor (District, Section, or Branch) | Location | Date | Number of Student Papers |
|---|---|---|---|
| 1 | Springfield, Mass. (North Eastern District meeting) | 5/3–5/39 | 15 |
| 8 and 9, University of British Columbia | San Francisco, Calif. (Pacific Coast convention) | 6/26–30/39 | 11 |
| 5 | Minneapolis, Minn. (Great Lakes District meeting) | 9/18/39 | 13 |
| 4 | Mississippi State College, State College | 4/11–13/40 | 6 |
| 6 | University of North Dakota, Grand Forks | 4/19–20/40 | 9 |
| 7 | Texas Technological College, Lubbock | 4/19–20/40 | |
| 2 | Swarthmore College, Swarthmore, Pa. | 4/22/40 | 5 |
| 3 and New York Section | Pratt Institute, Brooklyn, N. Y. | 4/25/40 | 7 |

urged that each Branch celebrate in some appropriate manner the 75th birthday of Doctor Charles F. Scott, originator of the plan for organizing Student Branches. A Charles F. Scott jubilee committee was organized with A. C. Stevens as chairman. The committee had a motion-picture film of Professor Scott prepared, and this and the film taken several years ago in the "past-presidents series" were made available to the Branches. They were shown at about 75 Branch meetings, many of which were joint meetings with other Branches and Sections.

The committee appointed in January 1939 to prepare copy for a second edition of the pamphlet "The Electrical Engineer," representing the Sections committee and the committee on Student Branches, distributed 188 copies of a revised manuscript to educators and others interested for comment. The 61 replies received were studied and the suggestions incorporated in so far as seemed advisable. Distribution of single copies in printed form was made about March 15 to Sections, Branches, and a large number of high schools. Up to April 30, orders had been received for 2,109 additional copies.

The committee on safety again suggested that each Branch have a meeting devoted to prevention of accidents or remedial measures after electric shocks. Many Branches carried out the suggestion.

Student technical sessions in connection with regular Institute meetings were held as follows: North Eastern District meeting, Springfield, Mass., May 3–5, two parallel sessions, 15 papers, two prizes at each session; summer-Pacific Coast convention, San Francisco, Calif., June 26–30, two sessions, 11 papers; Great Lakes District meeting, Minneapolis, Minn., September 27–29, one session, 13 papers.

The College of the City of New York held a smoker in February in the form of an inter-Branch get-together to encourage acquaintance and correlation of activities among the Branches in the city and vicinity. In the attendance of more than 100, seven Branches were represented, with a total of 40 from the visiting Branches.

The Branches in the Middle Eastern District have co-operated in the preparation and distribution of a mimeographed news sheet on their activities.

Tables IV and V contain information on Branch meetings. Table VI gives a record of co-operation between Sections and Branches, showing participation by 26 Sections and 39 Branches, as compared with 20 Sections and 30 Branches for the preceding year. Tables VII and VIII present summarized data on student conferences and conventions.

# National • • • •

## Pacific Coast Convention to Be Held in Los Angeles

Arrangements for the 1940 AIEE Pacific Coast convention, which will be held in Los Angeles, Calif., August 27–30, are now practically complete, according to N. B. Hinson, general chairman. The Ambassador Hotel, famous for its Cocoanut Grove, has been chosen for the convention headquarters. The dates are an ideal time for members throughout the country to plan their vacation trips. For women guests shopping, sightseeing tours, and other events of interest will be arranged.

The opening session will be addressed by Professor R. W. Sorensen, nominee for AIEE president for 1940–41, and the principal speaker will be Douglas Shearer, sound director of Metro-Goldwyn-Mayer Studios, who will discuss many interesting phases of motion-picture production.

The tentative technical program is comprised of five sessions and one conference on governors and frequency control. Technical sessions are on the following subjects: protective devices; instruments, measurements, and basic sciences; power transmission and distribution; electrical machinery; and a joint session with the Institute of Radio Engineers on communication and related subjects. The protective-devices session is expected to be outstanding, as there will be several papers presented on new design of circuit breakers and new relay applications. Present indications are that the sessions will be unique, in that every paper will be presented by the author. In addition, there will be student sessions and a student and counselor dinner and conference.

There are many points of interest in and around Los Angeles available for inspection trips, such as the 200-inch telescope at Mt. Palomar, 100-inch telescope at Mt. Wilson, Boulder Dam, NBC and Columbia broadcasting studios, Metropolitan Aqueduct, new receiving stations for Boulder Dam power, the Griffith Park Planetarium, and others.

Special emphasis is being placed on sports—tennis, golf, swimming, and others. The annual play for the Fisken golf cup will take place at The Riviera Country Club.

## National Prize Awards for 1939 Papers Announced

The AIEE committee on the award of Institute prizes, after considering all eligible papers, has announced the national prize awards for papers presented during 1939. On all except Branch papers the committee had the benefit of recommendations from the chairmen of technical committees on papers in their respective fields. No award is being made for best paper in public relations and education, since no eligible papers were presented during 1939. The prizes will be presented at the annual meeting of the Institute, June 24, 1940, during the forthcoming summer convention at Swampscott, Mass. The committee consists of J. W. Barker, *chairman*, W. S. Davidson, H. S. Osborne, I. Melville Stein.

Papers and authors receiving awards in the various classifications are:

*Best Paper in Engineering Practice:* Prize was awarded to F. J. Scuitder (M'25) and John N. Reynolds, Bell Telephone Laboratories, for their paper on "Crossbar Dial Telephone Switching System", presented at the winter convention, January 23–27, 1939, and published in the 1939 TRANSACTIONS (May section) pages 179–92. Honorable mention was made of the paper on "Pennsylvania Railroad, New York-Washington-Harrisburg Electrification, Relay Protection of Power Supply System", by E. L. Harder (A'30) Westinghouse Electric and Manufacturing Company, presented at the 1939 winter convention, and published in the 1939 TRANSACTIONS (June section) pages 266–73; and of the paper "A 12-Channel Carrier Telephone System for Open-Wire Lines", by B. W. Kendall (M'18, F'29) and H. A. Affel (A'18, M'23) Bell Telephone Laboratories, presented at the 1939 winter convention and published in the 1939 TRANSACTIONS (July section) pages 351–60.

*Best Paper in Theory and Research:* Prize was awarded to F. C. Holtz (A'16, M'29) Sangamo Electric Company, for his paper on "The Anomalous Behavior of the Moving Systems of Single-Phase A-C Watt-Hour Meters at No Load", presented at the combined summer and Pacific Coast convention, San Francisco, Calif., June 26–30, 1939, and published in the TRANSACTIONS section of ELECTRICAL ENGINEERING, February 1940, pages 116–21. Honorable mention was made of the paper "Subharmonics in Circuits Containing Iron-Cored Inductors—II", by Irven Travis (A'32) University of Pennsylvania, presented at the 1939 winter convention and published in the 1939 TRANSACTIONS, pages 735–42; and of the paper "A New Time Standard" by H. E. Warren (A'02) Warren Telechron Company, presented at the 1939 summer and Pacific Coast convention and published in the TRANSACTIONS section of ELECTRICAL ENGINEERING, March 1940, pages 137–41.

*Initial Paper:* Prize was awarded to W. C. Johnson (A'35) Princeton University, for his paper on "Predetermination of Temperatures in Resistance Welds", presented at the 1939 winter convention and published in the 1939 TRANSACTIONS, pages 845–53. Honorable mention was made of the paper "Breakdown Studies in Compressed Gases" by A. H. Howell (A'35), Massachusetts Institute of Technology, presented at the 1939 winter convention and published in the 1939 TRANSACTIONS (May section) pages 193–204; and of the paper "Signal System, Interlocking Plants, and Automatic Train Control on the San Francisco-Oakland Bay Bridge Railway" by C. R. Davis A'36) California State Public Works Department, presented at the 1939 summer and Pacific Coast convention and published in the TRANSACTIONS section of ELECTRICAL ENGINEERING, March 1940, pages 158–64.

*Branch Paper:* The prize was awarded jointly to W. N. Brown, Jr., and E. W. Sheridan, Massachusetts Institute of Technology, for their paper on "Frequency-Selective Feedback for Improvement of Acoustical Response of an Audio-Frequency Sound System" and to E. C. Dench, Worcester Polytechnic Institute, for his paper on "The 'Glo-Relay', a New Method of Initiating Vapor Discharges".

Awards being made by the various Districts for 1939 papers will be announced in future issues, as the information becomes available.

# Branch • • • •

## Annual Student Conference Held by District 4 Branches

The annual conference of AIEE Student Branches in the Southern District (4) was held at Mississippi State College, State College, Miss., April 11–13, 1940. About 175 delegates attended the conference, at which Dean L. L. Patterson, District chairman of student activities, presided. The program included a general session and a technical session on April 12, a business meeting April 13, a smoker April 11, given by the local chapter of Tau Beta Pi, and the annual banquet April 12. President F. Malcolm Farmer was the principal speaker at the opening session.

The six papers selected by the papers committee for final competition for the three cash prizes given by the Mississippi State College Branch, and presented at the technical session, were:

TECHNOLOGICAL UNEMPLOYMENT—AN ENGINEERING PROBLEM, **E. A. Kehoe**, University of Alabama

THE SANTEE-COOPER PROJECT, **R. G. Fellers**, University of South Carolina

THIRTY-PHASE MERCURY-ARC RECTIFICATION, **J. S. McQueen**, University of Tennessee

THE T RAY (THE TUBE RAY), **L. L. Anderson**, Speed Scientific School, University of Louisville

COMPARISON OF THE OPERATION OF 220-VOLT METERS ON 220- AND 208-VOLT CIRCUITS, **J. W. Wilkinson** and **W. M. Healy, Jr.**, North Carolina State College

CONSTRUCTION OF A FREQUENCY STANDARD, **M. M. Zemek**, Georgia School of Technology

First prize ($15) was awarded to L. L. Anderson; second prize ($10) to J. W. Wilkinson and W. M. Healy, Jr.; third prize ($5) to E. A. Kehoe. Awards were made at the annual banquet, at which District Vice-President Fred R. Maxwell, Jr., presided and G. W. Thaxton (M'36) chief engineer, Rural Electrification Administration, was principal speaker.

At the business meeting, April 13, distribution of District-conference prize-winning papers to the other Branches in the District was discussed. The conference voted to ask the AIEE board of directors to allow the Branch of which the student winning first prize is a member to use not more than $5 of its annual allotment for printing and mailing copies of the winning paper. Selection of papers for presentation at District conferences was discussed and it was voted to leave to the discretion of the papers committee the number to be presented.

The conference voted to meet next year at Tuscaloosa, Ala., at the invitation of the University of Alabama. Proposals for a meeting at Tulane University, New Orleans, in connection with the next District meeting to be held in that city, or at the University of Kentucky, Lexington, if a District meeting is not held in New Orleans in 1941, were favorably considered.

Professor W. J. Miller, University of Alabama, was elected District chairman of student activities for the term beginning August 1, 1940, and designated as counselor delegate of the Southern District to the forthcoming summer convention.

## Conference on Student Activities Held by District 6

The 13th annual conference on student activities of the North Central District (6) was held April 19–20, 1940, at the University of North Dakota, Grand Forks. The program included two technical sessions, a general session, a business meeting of Student Branch counselors, and a banquet.

At the technical sessions on April 19, the following student papers were presented:

*Morning session*

TEST OF INSULATION BY POWER-FACTOR AND WATTS-LOSS METHOD. **Donald Riggs,** South Dakota State School of Mines

THE ACCENTUATION OF HARMONICS BY STATIC CONDENSERS USED FOR POWER-FACTOR CORRECTION. **H. A. Woll,** North Dakota State College

FREQUENCY MODULATION. **Clifford Thomforde,** University of North Dakota

FREQUENCY MODULATION. **Franklin Ordung,** South Dakota State College

APPLICATION OF THYRATRON TUBES. **Kenneth Beach,** University of Wyoming

*Afternoon session*

FREQUENCY CONTROL. **Stanley Case,** Colorado State College

HIGH-STABILITY GAIN IN REGENERATIVE AMPLIFIERS. **Harold Crispell** and **Clyde Hartman,** University of Colorado

ALL-IRON TRANSFORMERS AND REACTORS. **Robert Boyles** and **William Hinch,** University of Denver

DESIGN OF A LOW-COST AMATEUR RADIO TRANSMITTER. **H. W. Berry,** University of Nebraska

Prize awards, announced at the banquet April 19, were as follows: District prize for Branch paper Stanley Case; first honorable mention, Harold Crispell and Clyde Hartman; second honorable mention, Franklin Ordung. Feature speaker at the banquet was District Vice-President A. L. Turner.

The business meeting of Student Branch counselors was attended by the following:

*Counselors:* G. H. Sechrist, University of Wyoming; F. B. Beatty, Colorado State College; H. B. Palmer, University of Colorado; B. E. Cohn, University of Denver; L. A. Bingham, University of Nebraska; H. S. Rush, North Dakota State College; W. H. Gamble, South Dakota State College; J. O. Kammerman, South Dakota State School of Mines; H. F. Rice, University of North Dakota.

*Others:* Dean H. M. Crothers, South Dakota State College; A. L. Turner, District vice-president; I. M. Ellestad, District secretary.

The meeting voted to hold the 1941 conference on student activities at the University of Denver, Denver, Colo., April 18–19. Professor H. F. Rice, University of North Dakota, was elected chairman of the District committee on student activities for 1940–41 and counselor delegate to the 1940 summer convention. Changes in regulations governing student prize papers were discussed, and the recommendation made that Districts set their own qualifications for awards, but follow national rules in judging papers.

# Standards • • •

## Report on Wave Form in Dielectric Power-Factor Measurements

As a result of a request of the ASA committee on insulated wires and cables, the AIEE committee on instruments and measurements appointed a subcommittee* to study the effect of wave form in power-factor measurements and to suggest which of the following terms should be used: form factor, deviation factor, or distortion factor. The report which follows applies to power-factor tests made on commercial electrical insulating materials and insulation of electrical equipment where such tests are required by specifications. The recommendations apply to tests made at audio and radio frequencies as well as to tests made at power frequencies. Where very accurate measurements are required, as in certain research investigations, greater restrictions on wave form and measuring equipment are necessary as indicated.

### FORM FACTOR

As given by AIEE definition, 05.05.260,

"The form factor of a symmetrical alternating quantity is the ratio of the effective value of the quantity to its half-period average value."

The form factor for a pure sine wave is 1.11. The form factor for a peaked wave is higher than 1.11; for a flat-topped or a saddled wave it is less than 1.11. Although form factor gives an idea of the wave shape, it does not disclose the extent of harmonic content. A form factor different from 1.11 indicates presence of harmonics, yet a form factor of 1.11 does not prove the absence of harmonics, inasmuch as distorted wave forms are possible which have a ratio of effective to average value of 1.11.

In view of this objection, form factor is not recommended for specifying wave form in dielectric-power-factor measurements.

### DEVIATION FACTOR

As given by AIEE definition, 10.95.420,

"The deviation factor of a wave is the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superposed in such a way as to make this maximum difference as small as possible."

The deviation factor indicates presence of distortion, and fixing an upper limit to the deviation factor limits the peak voltage of the wave. It does not indicate the relative amount of fundamental and harmonic components to that of the total wave.

The deviation factor requires a trace of the wave form.

In view of these objections, deviation factor is not recommended for specifying wave form in dielectric power-factor measurements.

### DISTORTION FACTOR

As given by AIEE definition, 10.95.430,

"The distortion factor of a voltage wave is the ratio of the effective value of the residue after the elimination of the fundamental to the effective value of the original wave."

The distortion factor gives a measure of the harmonic content present in proportion to the total wave. Fixing an upper limit to distortion factor limits the maximum rms value for the harmonic content with reference to the total wave. The distortion factor may be measured with commercially available equipment, and a trace of the wave form is not required.

In view of the advantages in the use of distortion factor as compared to form factor or deviation factor, it is recommended that distortion factor be adopted for specifying wave form in dielectric-power-factor measurements.

### CREST FACTOR

The crest factor of a wave is defined as the ratio of the maximum value to the effective value of the wave. The crest factor for a pure sine wave is 1.414; for a peaked wave, greater than 1.414; for a flat-topped or a saddled wave, less than 1.414.

### CREST-DEVIATION FACTOR

The crest-deviation factor of a wave is the departure of the crest factor from 1.414, calculated in percentage. For a pure sine wave it is zero; for a peaked wave, greater than zero; for a flat-topped or a saddled wave, less than zero. The crest-deviation factor is never greater than the deviation factor, yet fixing an upper limit to the crest-deviation factor limits the peak voltage of the wave. It may be determined with commercially available equipment, and a trace of the wave form is not required.

For the particular case of a single harmonic distorting a wave in a peaked direction, both the distortion factor and the maximum crest-deviation factor closely follow the percentage of the harmonic in the wave, as may be seen from the tabulation below:

**Distortion Factor and Maximum Crest-Deviation Factor for Varying Amounts of a Single Harmonic**

| Harmonic as Percentage of Fundamental | Distortion Factor (Per Cent) | Crest Factor, Peaked Wave | Crest-Deviation Factor (Per Cent) |
|---|---|---|---|
| 0 | 0 | 1.414 | 0 |
| 5 | 4.994 | 1.483 | 4.9 |
| 10 | 9.950 | 1.548 | 9.5 |

When more than one harmonic is present in the wave, it is theoretically possible for the crest-deviation factor considerably to exceed the distortion factor. In the case of actual alternator wave shapes, however, extensive analyses have indicated that the ratio of the crest-deviation factor to the distortion factor is usually less than 1.4.

The advisability of placing a limitation on the crest-deviation factor of voltage waves used in measuring dielectric power factor is discussed later in the report.

### EFFECT OF APPARATUS UNDER TEST ON WAVE FORM

When the charging current of the apparatus under test is such that it might appreciably increase the distortion of the voltage wave, the wave form should be determined with the apparatus under test or an equivalent capacitance connected to the voltage source.

### EFFECT OF HARMONICS ON DIELECTRIC POWER-FACTOR MEASUREMENTS

When harmonics are present in the voltage of the power source, the measured power factor of a dielectric depends on:

1. Variation of dielectric properties with frequency
2. Variation of dielectric properties with voltage
3. Method of measurement
   - *A.* By measurement of power loss
     - (*a*). Calorimeter
     - (*b*). Electrometer
     - (*c*). Dynamometer

* Membership of the subcommittee: G. M. L. Sommerman, *chairman*, E. D. Doyle, Paul MacGahan, D. F. Miner, E. J. Rutan, E. H. Salter, C. T. Weller. (A. C. Seletzky, deceased, was chairman until May 1938.)

*B.* By measurement with a power-factor bridge

(a). Dependence of bridge balance on frequency and the frequency response of the null detector

In general, the power factor of a dielectric varies with frequency, but as long as the dielectric currents vary nearly linearly with voltage, and there is no appreciable heating caused by the harmonics, the power factor of the dielectric engendered by the fundamental frequency will be independent of harmonic content. Thus, measurement of power factor by any method which is not responsive to the harmonic frequencies will permit a determination independent of harmonic content and a function of fundamental frequency only.

If the voltage applied to the dielectric is of magnitude sufficient to produce ionizing gradients, a peaked wave might produce greater ionization than an equivalent sine wave. This suggests that a limitation be placed on the crest-deviation factor of the voltage wave. It is not necessary that the limitation be very drastic, however, because ionization in dielectrics usually increases only gradually with increasing voltage. It is therefore recommended that the crest-deviation factor be limited to less than ten per cent.

When the power factor of a dielectric is determined by measuring the dielectric loss with a calorimeter, electrometer, or dynamometer, the value obtained generally will be dependent on the distortion factor of the voltage wave. This is also true to some extent in power-factor-bridge measurements when a null detector with a broad frequency response is used. If the harmonics are known, and sufficient experimental data are available on the variation of dielectric properties with frequency for the dielectric under test, the power factor for a sine wave of fundamental frequency may be computed by calculations of the dielectric loss involved for each harmonic voltage. A comprehensive investigation of this phase of the question, sufficiently exhaustive to be of value, would require the investigation of different types of dielectrics with various kinds of wave forms, containing varying percentages of various harmonics at various amplitudes and phase angles. It is suggested that such an investigation would make an interesting research problem. This subcommittee, however, does not consider it necessary to undertake the investigation because in many cases it has been found that a small amount of distortion produces only a small error in power factor, and because this source of error can be effectively eliminated by the use of measuring apparatus which is not responsive to harmonic frequencies.

In bridge measurements, the effect of harmonics may be eliminated by making the null detector irresponsive to the harmonic frequencies. For example, a null detector tuned to the fundamental frequency or a tuned circuit ahead of the null detector may be used. A precaution which should be observed in this connection, if an amplifier is used ahead of the apparatus in which the frequency response is limited, is the necessity for linear amplification; otherwise harmonics can combine to produce a voltage of fundamental frequency at the amplifier output (W. M. Goodhue, *Journal* of the Franklin Institute, volume 217, 1934, page 87).

As far as could be ascertained from any indications in the literature, or from the experience and knowledge of any of the members of the subcommittee, considerable distortion does not influence to any appreciable extent the power-factor readings obtained with power-factor bridges equipped with properly tuned null-detector circuits. Available test data in this connection indicate that a distortion factor of ten per cent will not appreciably impair the accuracy of power-factor readings. On this basis it is safe to place a limiting value of five per cent to distortion factor.

RECOMMENDATIONS

As a result of these considerations, this subcommittee recommends that: Distortion factor should be used for the specification of voltage wave form of the power source employed in measurements of the power factor of dielectrics.

The distortion factor should be limited to five per cent.

The crest factor should not exceed that of a sine wave by more than ten per cent.

When accurate dielectric power-factor measurements are required, a sine-wave voltage source should be used, or measuring equipment which is insensitive to harmonic frequencies should be used.

# Personal • • •

**E. C. Crittenden** (A'19, M'22) assistant director of the National Bureau of Standards, Washington, D. C., has been elected president of the United States National Committee of the International Electrotechnical Commission. Born December 19, 1880, at Oswayo, Pa., he received the degree of bachelor of arts at Cornell University, Ithaca, N. Y., where he later did graduate work in physics and mathematics while holding the position of instructor in physics, 1905–09. He was appointed assistant physicist at the Bureau of Standards in 1909 and later associate physicist and physicist. In 1921 he was made chief of the electrical section and since 1933 has been assistant director of the Bureau. He has represented the Bureau on the standards council of the American Standards Association since 1924, and has been a member of the electrical standards committee of the ASA and the USNC since 1931. He is a past president of the United States National Committee of the International Commission on Illumination, of the Illuminating Engineering Society, and of the Optical Society of America, and has also been active in the American Physical Society, American Institute of Physics, and American Association for the Advancement of Science. He was chairman of the AIEE committee on research 1938–39.

**L. V. Bewley** (A'27, M'37) has been appointed professor and head of the department of electrical engineering, Lehigh University, Bethlehem, Pa., effective September 1, 1940. He was born December 19, 1898, at Republic, Wash., and received the degree of bachelor of science in electrical engineering from the University of Washington in 1923, and that of master of science from Union College in 1927. He became associated with the General Electric Company in 1923 and has continued with the company ever since, his present position being research engineer at Pittsfield, Mass. He completed the General Electric test course, advanced course, and co-operative course with Union College, the last in preparation for the master's degree, and has taught for a number of years in the company's courses for engineering graduates. He is the author of a book and many technical papers. In 1932 he received the AIEE national best paper prize and he has received the Charles A. Coffin Award for "outstanding contributions to the knowledge of lightning and traveling-wave phenomena". He is a member of Sigma Xi and Tau Beta Pi.

**H. B. Bryans** (M'17, F'18) executive vice-president, Philadelphia Electric Company, Philadelphia, Pa., has been made a director of the company. He has been a vice-president since 1929 and executive vice-president since 1938. **Raymond Bailey** (A'17, M'26) formerly assistant electrical engineer in the electrical-engineering division of the company, has been appointed assistant purchasing agent. Mr. Bailey, who is chairman of the AIEE committee on power transmission and distribution, has been with the company since his graduation in 1916. He is succeeded as assistant electrical engineer by **L. R. Gaty** (A'39) formerly assistant to the general superintendent of transmission and distribution, suburban divisions. **C. E. Nelson** (M'35) formerly superintendent, service maintenance division, has been appointed division superintendent of the eastern division of the company.

**Eugene Vinet** (A'13, M'25) has been appointed executive secretary of the National Electrical Manufacturers Association. A native (1888) of Montreal, Can., he graduated in electrical engineering at McGill University in 1911. He has been associated with the Shawinigan Water and Power Company, Montreal; the Middle West Utilities Company, Chicago, Ill., and since 1931 with the Edison General Electric Appliance Company, Inc., Chicago.

**E. E. Kleinschmidt** (M'22) president, Kleinschmidt Laboratories, Inc., Highland Park, Ill., and **H. L. Krum** (A'12, F'27) Beverly Hills, Calif., vice-president, Teletype Corporation, Chicago, Ill., have been awarded jointly the Edward Longstreth Medal of the Franklin Institute "in consideration of their part in the development of a successful electrically operated duplicate typewriting machine now known as the teletypewriter."

**Roland Whitehurst** (A'20, M'21) formerly manager, Washington, D. C., branch, Electric Storage Battery Company, has been appointed assistant general sales manager of the company, with headquarters at Philadelphia. He has been with the company since 1908 and manager of the Washington branch since 1920. **J. A. Klingensmith** (A'38) formerly a member of the sales

staff in Washington, has been made manager of the branch.

**Mark Eldredge** (A'14, F'33) has resigned as director of the electrical division of the City of Memphis, Tenn., Light, Water, and Gas Division. He took the position in 1939 when the city took over the Memphis Power and Light Company, of which he had been chief engineer since 1924. Mr. Eldredge, who is a director of the Institute, has not announced his future plans.

**K. L. Howe** (A'28, F'36) has been made manager in charge of sales for the Seattle, Spokane, and Tacoma offices of the Westinghouse Electric and Manufacturing Company. He has been associated with the company since 1924, with headquarters in Seattle except for the period 1925–27 which he spent in East Pittsburgh and the past year, during which he was at San Francisco.

**A. M. Musgrove** (A'30, M'37) formerly assistant distribution manager, Bergen division, Public Service Electric and Gas Company of New Jersey, has been transferred to the Newark headquarters of the company, as assistant engineer in the department of distribution engineering.

**M. P. Doran** (A'38) formerly junior engineer, Harry Alexander, Inc., Washington, D. C., is now employed as electrical superintendent for Arundle-Consolidated Engineering Companies at the United States Naval Air Station, San Juan, Puerto Rico.

**J. C. Gaylord** (A'11, M'26) formerly hydro engineer, Southern California Edison Company, Ltd., Los Angeles, Calif., has been appointed superintendent of hydro generation.

**R. E. Roesch** (A'25, M'38) formerly division engineer, Virginia Public Service Company, Alexandria, is now associated with Stone and Webster Engineering Corporation, Boston, Mass.

**L. G. Snyder** (A'23, M'35) formerly sales manager, Landis and Gyr, New York, N. Y., is now sales manager in charge of central-station sales, Metropolitan Device Corporation, Brooklyn, N. Y.

**W. C. Kalb** (A'13, F'40) formerly in the advertising department of the Carbon sales division, National Carbon Company, Inc., Cleveland, Ohio, has been made commercial engineer of the division.

**F. B. Doolittle** (A'26, M'33) formerly distribution engineer, Southern California Edison Company, Ltd., Los Angeles, Calif., has been assigned to general engineering work with the title of electrical engineer.

**V. B. Wilfley** (A'26, M'37) engineering supervisor, Westinghouse Electric and Manufacturing Company, has been transferred from Portland, Ore., to Seattle, Wash., by the company.

**G. K. Bennison** (A'39) has been employed as an assistant in the ceramics laboratory, AC Spark Plug Division, General Motors Corporation, Flint, Mich.

**H. P. Liversidge** (A'12, M'17) president, Philadelphia (Pa.) Electric Company, has been elected a director of the United Gas Improvement Company, Philadelphia.

## Obituary • • •

**Edwin Fitch Northrup** (A'01, M'09, F'13) vice-president and technical adviser, Ajax Electrothermic Corporation, Trenton, N. J., died at Princeton, N. J., April 29, 1940. He was born February 23, 1866, at Syracuse, N. Y., received the degree of bachelor of arts from Amherst College in 1891, and was a graduate student in physics at Cornell University and at Johns Hopkins University. At the latter he held fellowships for two years and received the degree of doctor of philosophy in 1895. He spent the following year in practical electrical work in Utah and Montana, and in 1896 was appointed associate professor and head of the department of physics at the University of Texas, Austin. During 1897–98 he was employed in the testing department of the Westinghouse Electric and Manufacturing Company, leaving to assist in the development of the Rowland multiplex printing telegraph system. He was chief engineer of the Rowland Telegraph Company 1898–1902. He was one of the founders of the Leeds and Northrup Company, manufacturers of electrical instruments, Philadelphia, Pa., and its secretary 1903–10. In 1910 he became assistant professor of physics at Princeton University, Princeton, N. J., and continued his teaching and research there until 1919. During this period he began the development of the coreless induction furnace, which is regarded as perhaps his leading contribution. From 1916 to 1920 he was president and technical adviser of the Pyroelectric Instrument Company, which he founded, and in 1920 he assumed the position with the Ajax Electrothermic Corporation which he held at the time of his death. He held over 100 United States patents, was the author of various textbooks and many technical papers, and was also a member of the American Association for the Advancement of Science, Electrochemical Society, Franklin Institute, and Inventors' Guild. He received the Bronze Medal of the Paris Exposition, 1900; the Edward Longstreth Medal, 1912; the Elliott Cresson Medal, 1916; and the Edward Goodrich Acheson Gold Medal, 1931. He was honored in 1932 as one of the 12 leading American inventors of the day and recently was cited as a "modern pioneer".

**David Barker Rushmore** (A'95, M'02, F'13) retired consulting engineer, General Electric Company, died May 5, 1940, at New York, N. Y. He was born at Old Westbury, N. Y., August 21, 1873, and received the degrees of bachelor of science in engineering, Swarthmore College, 1894; mechanical engineer (electrical engineering) Cornell University, 1895; civil engineer, Swarthmore, 1897; and the honorary degree of doctor of science from Swarthmore in 1923. In 1895–96 he was an inspector for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and in 1896–97 foreman of the testing department, Royal Electric Company, Montreal, Que., Can. After recovery from an accident he became a design engineer for the Stanley Electric Manufacturing Company, Pittsfield, Mass., continuing in that position until 1905 when he went with the General Electric Company, Schenectady, N. Y., as an engineer in the power and mining department. He became chief engineer of the department in 1907, and held that position until 1922. He was consulting engineer for the company 1922–25, until his retirement. He was president of the Espanol-Americano Company, and vice-president and director of the Spanish-American Fruit Company. He was a delegate to several meetings of the World Power Conference, and was also a member of The American Society of Mechanical Engineers, American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, Electrochemical Society, American Association for the Advancement of Science, Société Française des Électriciens, and other organizations. He was the author of one book and many technical papers.

**Walter S. Rugg** (A'02, M'13) retired vice-president, Westinghouse Electric and Manufacturing Company, died in New York, N. Y., April 25, 1940. He was born in Broadhead, Wis., in 1866, and received the degree of bachelor of science from Laurence College in 1886 and that of master of science from Cornell University in 1892. Later that year he went with the Westinghouse company as a student engineer at Pittsburgh, Pa., continuing with the company until his retirement. He was transferred to Chicago, Ill., as district engineer in 1895, and in 1901 came to New York as special sales engineer. He was made manager of the New York office in 1909, continuing in that position until 1917, when he was made manager of the railway department at East Pittsburgh. Shortly afterward he was made manager of the marine department also, and in 1922 became general sales manager of the company. He was made a vice-president in 1925, in charge of engineering and sales activities. He retired in 1935. He was a manager of the AIEE 1910–13, and was also a member of the American Association for the Advancement of Science, Franklin Institute, and other organizations.

**Ira Walton Henry** (A'01, M'13) consulting engineer, New York, N. Y., died in Old Greenwich, Conn., April 25, 1940. He was born at Albany, N. Y., in 1869 and educated in Boston, Mass. From 1889 to 1892 he was an electrician at the New York central station of the Thomson-Houston Electric Company, and for the next four years was an electrical engineer for the Bishop Gutta Percha Company, manufacturing electric wires and cables. In 1896 he became a cable engineer for the Safety Insulated Wire and Cable Company, designing, manufacturing, and laying submarine cables. He later went into private practice as a consulting engineer. He devised a system of electrically lighted buoys used in New York Harbor for some years, and developed various other inventions. During the last ten years he had been chiefly concerned with the development of patents on electrical processes in oil refining. For this purpose he had formed the Ionizing Corporation of America, of which he was president at the time of his death.

**John Theodore Graff** (A'21, M'27) assistant vice-president, Chesapeake and Potomac Telephone Companies, Washington,

D. C., died March 18, 1940. He was born December 1, 1877, at Washington, and received the degree of mechanical engineer from Cornell University in 1900. He was employed immediately after graduation by the Western Electric Company, New York, N. Y., and in 1901 was transferred to the New York and Pennsylvania Telephone and Telegraph Company, as wire chief at Binghamton, N. Y. The following year he became wire chief at Baltimore, Md., for the Chesapeake and Potomac Telephone Company of Baltimore City, becoming district plant supervisor in 1909 and division plant engineer in 1913. During 1917–19 he served as captain in the Signal Corps of the United States Army, and was commissioned as major in the reserve corps on leaving the service. He returned to the office of the general plant manager of the Chesapeake and Potomac Telephone Companies in Baltimore. He was appointed general plant supervisor in 1927, chief engineer for Virginia in 1929, and assistant vice-president in 1939. He was chairman of the AIEE Virginia Section, 1933–34.

**George Clayton Dill** (A'13, M'22) electrical engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., died April 1, 1940. He was born September 24, 1884, at Swanton, Ohio, and received the degree of bachelor of science in electrical engineering from Purdue University in 1909. After six months as an apprentice with the Fairbanks Morse Electrical Company, Indianapolis, Ind., he became an apprentice in the switchboard-engineering department of the Westinghouse company. In 1911 he became an electrical engineer in the supply-engineering department, handling design and application of lightning arresters, with particular attention to electrolytic arresters. He continued in that work until 1932, when he was transferred to the switchgear-engineering department of the Westinghouse company. He was the author of various papers for technical publications.

**Julio Lagomasino, Jr.** (A'38) engineer, Companiá Cuba de Electricidad, Havana, Cuba, died recently, according to information just received at Institute headquarters. He was born November 15, 1912, at Havana, and received the degree of bachelor of science in electrical engineering at the Georgia School of Technology in 1937. Since 1937 he had been employed by the Compania Cuba de Electricidad, as student engineer and engineer.

# Membership • •

## Recommended for Transfer

The board of examiners, at its meeting on May 16, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

**To Grade of Fellow**

Copeland, C. A., assistant electrical engineer, Bureau of Power and Light, Los Angeles, Calif.

Dible, H. J., transmission and protection engineer, The Ohio Bell Telephone Company, Cleveland.

LeClair, T. G., supervising development engineer, Commonwealth Edison Company, Chicago, Ill.

Rollins, N. A., plant installation engineer, Commonwealth Edison Company, Chicago, Ill.

Smith, W. C., Engineer, General Electric Company, San Francisco, Calif.

5 to Grade of Fellow

**To Grade of Member**

Baker, R. M., research engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Bower, G. W., district superintendent, Public Service Electric and Gas Company, Camden, N. J.

Boyce, H. A., district plant engineer, American Telephone and Telegraph Company, Cleveland, Ohio.

Diehl, P. V., relay engineer, Oklahoma Gas and Electric Company, Oklahoma City.

Evans, D. G., vice-president, Wisconsin Gas and Electric Company, Racine.

Giesger, J. A., assistant electrical engineer, Eastman Kodak Company, Rochester, N. Y.

Grimm, G. A., chief load dispatcher, Indiana Service Corporation, Fort Wayne.

Hazen, H. L., professor of electrical engineering, Massachusetts Institute of Technology, Cambridge.

Henderson, C. W., professor of electrical engineering, Syracuse University, Syracuse, N. Y.

Hyatt, P., general plant supervisor, Illinois Bell Telephone Company, Chicago, Ill.

Knotts, C. L., engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Millard, T. O., application engineer, General Electric Company, Chicago, Ill.

Miller, S. O., chief electrical engineer, Lower Colorado River Authority, Austin, Tex.

Olson, P. R., electrical engineer, American Steel and Wire Company, Worcester, Mass.

Parrott, W. G., assistant electrical engineer, Tennessee Valley Authority, Chattanooga, Tenn.

Read, C. A., executive assistant, General Electric Company, Pittsfield, Mass.

Smith, H. E., line design engineer, Commonwealth Edison Company, Chicago, Ill.

Vivell, A. E., assistant professor, Princeton University, Princeton, N. J.

Wiheard, W. W., station installation engineer, Commonwealth Edison Company, Chicago, Ill.

19 to Grade of Member

## Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of the candidates should so inform the national secretary before June 30, 1940, or August 31, 1940, if the applicant resides outside of the United States or Canada.

**United States and Canada**

1. NORTH EASTERN

Bartelink, E. H. B., General Electric Company, Schenectady, N. Y.

Edwards, R. D., Jr., 92 Warwick Avenue, Bridgeport, Conn.

Falk, M. C., Central New York Power Company, Syracuse, N. Y.

Larrick, C. V., General Electric Company, Schenectady, N. Y.

Winsor, L. P., Harvard University, Cambridge, Mass.

2. MIDDLE EASTERN

Agner, O. B., Westinghouse Electric and Manufacturing Company, Philadelphia, Pa.

Bray, F. E., Jr., Sun Shipbuilding & Dry Dock Company, Chester, Pa.

Cleaves, R. D., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.

Cornbrooks, C. W., United States Maritime Commission, Washington, D. C.

Cramer, F. W. (Member), Carnegie Illinois Steel Corporation, Pittsburgh, Pa.

Hipp, J. E., Consolidated Gas Electric Light and Power Company of Baltimore, Baltimore, Md.

Leonard, S. E., National Broadcasting Company, Inc., Cleveland, Ohio.

Lucas, J. S., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

MacLane, G. L., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

McKee, F. L., Philadelphia Electric Company, Philadelphia, Pa.

Radecky, P. P., Hickok Electrical Instrument Company, Cleveland, Ohio.

Snyder, R. R., Hartman Electrical and Manufacturing Company, Mansfield, Ohio.

Van Liew, A. B., Utilities Service Company, Allentown, Pa.

Van Sickle, M. E. (Member), Pennsylvania Power and Light Company, Williamsport.

Wickline, F. H., Duquesne Light Company, Springdale, Pa.

Wyman, B. W., General Electric Company, Philadelphia, Pa.

3. NEW YORK CITY

Di Stadio, D., Western Electric Company, New York, N. Y.

Giordano, A. B., Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Kittredge, L. E., (Member), American Telephone and Telegraph Company, New York, N. Y.

Mahoney, J. J., Jr., Bell Telephone Laboratories, New York, N. Y.

Sattan, J. K., 11 Caroline Avenue, Clifton, N. J.

Shepardson, E., Colvinex Corporation, New York, N. Y.

Smith, A. B., National Electrical Manufacturers Association, New York, N. Y.

Swanson, G. F., Bell Telephone Laboratories, New York, N. Y.

4. SOUTHERN

Boone, W. H., Fairbanks Morse and Company, New Orleans, La.

Giersch, O. L. (Member), Duke Power Company, Charlotte, N. C.

Guy, E. H., Florida Power and Light Company, Miami.

Kendrick, W. H. (Member), South Carolina Electric and Gas Company, Columbia.

McMeekin, P. R. (Member), South Carolina Electric and Gas Company, Columbia.

Reeves, J. H., Jr., Westinghouse Electric and Manufacturing Company, Greenville, S. C.

Rodgers, W. S. (Member), South Carolina Electric and Gas Company, Columbia.

Ryscuck, J., Seaboard Air Line Railway, Norfolk, Va.

Stevenson, J. R. (Member), Memphis Light, Gas and Water Division, Memphis, Tenn.

von Bose, Max, Florida Power and Light Company, Miami.

Weeks, J. L. (Member), South Carolina Electric and Gas Company, Columbia.

5. GREAT LAKES

Dinius, K. E. (Member), Carnegie Illinois Steel Corporation, Chicago, Ill.

Drake, G. F. (Member), Woodward Governor Company, Rockford, Ill.

Judd, R. C., Peoples Light Company, Davenport, Iowa.

McConnell, R. C., Joseph R. Seagram and Sons, Inc., Lawrenceburg, Ind.

McCurdy, B. H., Commonwealth and Southern Corporation, Jackson, Michigan.

Olsen, S. R., Commonwealth and Southern Corporation, Jackson, Mich.

Sever, L. J., Commonwealth and Southern Corporation, Jackson, Mich.

6. NORTH CENTRAL

Wingfield, K. S. (Member), Public Works Administration, Kearney, Nebr.

7. SOUTH WEST

Donaldson, W. L., Texas Electric Service Company, Wichita Falls.

Hawkins, V. D., Arkansas Power and Light Company, Marion.

Learned, S. S. (Member), Phillips Petroleum Company, Bartlesville, Okla.

Weber, R. S. (Member), Rural Electrification Administration, Austin, Texas.

8. PACIFIC

Heintz, R. M. (Member), Jack Heintz, Ltd., Palo Alto, Calif.

Lidow, E., Emby Photographic Products, Inc., Los Angeles, Calif.

Miller, R. P. (Member), Miller Electric Construction Company, San Diego, Calif.

Van Meter, L. M., Pacific Gas and Electric Company, Oakland, Calif.

9. NORTH WEST

Brunzell, G. M., Washington Water Power Company, Davenport.

Crombry, R. R., Department of Lighting, Seattle, Wash.

Hiatt, D. L., Northwestern Electric Company, Portland, Ore.

Johnson, E. B., Washington Water Power Company, Okanogan.

Polhemus, J. H. (Member), Portland General Electric Company, Portland, Ore.

Thompson, V. N., Washington Water Power Company, Lewiston, Idaho.

10. CANADA

Bissett, D. P. M., 7214—105 A Street, Edmonton, Alberta, Canada.

Total, United States and Canada, 59

**Elsewhere**

Sharma, R. L., Raghunath Temple, Muzaffarabad, Kashmir, India.

Aras, B. K., Shikarpur Electric Supply Company, Ltd., Shikarpur, Sind, India.

Hirsch, W. (Member), Brazilian Telephone Company, Rio de Janeiro, Brazil, South America.

Benjamin, L., Power House, Veraval, Junagadh State, India.

Scheibe, W. K. (Member), Cia Minera de Oruro, Oruro, Bolivia, South America.

Mahanti, P. (Member), University College of Science and Technology, Calcutta, India.

Total, elsewhere, 6

Transactions

Preprint of Papers and Discussions Comprising Pages 321–368 of the 1940 Volume

# Upper-Air Weather Soundings by Radio

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**Synopsis:** A radio system for upper-air weather soundings with small unmanned balloons is described. The balloon instrument comprises elements for measuring pressure, temperature, and humidity, and a miniature radio transmitter; the latter converts the response of the measuring instruments into characteristic signals modulating the emitted radio wave and sends this wave to a ground station where the signals are measured and recorded. Details of the system are given and a discussion is given of the accuracy of the upper-air observations obtained and of the tolerances permissible for component elements of the system.

## I. Introduction

A RECENT significant advance in weather forecasting is based on the routine collection of upper-air data to heights of up to 25 kilometers by means of radio soundings. This paper describes a method of radio sounding now in widespread use and presents a discussion of the accuracy of the observations. This method has recently supplanted the use of airplanes carrying calibrated recording instruments for securing upper-air data.

The radio-sonde system employs an instrument carried aloft on a small unmanned balloon, and ground-station receiving and recording equipment. The balloon instrument, called a radio sonde, comprises elements for the measurement of barometric pressure, air temperature, and humidity; a radio transmitter and power supply; and means for impressing on the radio transmitter modulating frequencies which have predetermined relationships to the values of the factors measured. At the ground station, the frequencies of the received signals are measured and recorded automatically, producing a chart of temperature and humidity plotted against pressure.

Figure 1 (at the left) shows a radio sonde just as the sounding has begun. The balloon is of latex rubber and is inflated with helium or hydrogen gas to give a lift of about one kilogram in excess of the over-all weight of the sounding equipment. An ascensional rate of approximately 200 meters per minute is obtained. The diameter of the balloon is about 5 feet at surface pressure and reaches a value of the order of 15 feet before bursting; the corresponding maximum altitude ranges from 20 to 25 kilometers. A small silk parachute between the balloon and the instrument operates when the balloon bursts, bringing the instrument back to earth at a safe rate of descent. See figure 1 (at the right). The wind may carry the balloon up to 200 miles from the point of release before the equipment returns to the earth; nevertheless, more than a third of the radio sondes released are recovered and are used over again.

The potential value of our method of radio sounding was determined in experimental use by the Weather Bureau, Navy Department, and Coast Guard at 12 stations during 1938–39. The service has since been expanded to include some 30 land and 5 shipboard stations; more than 1,000 radio sondes being used monthly.

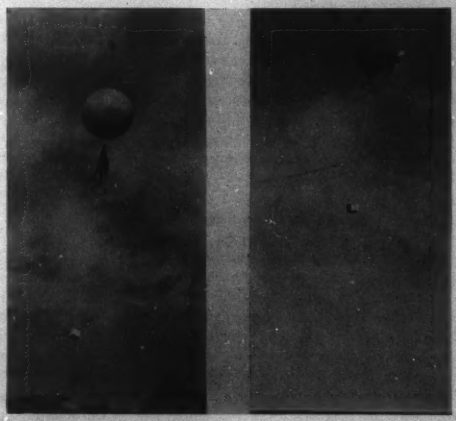

**Figure 1. Radio sounding equipment during ascent and descent**

This paper deals with an improved form of radio sonde using this method which incorporates a new device for measuring relative humidity; the improved instrument has been introduced at nine stations and its use at one more is contemplated in the near future.

A bibliography on radio methods for upper-air soundings was given in an earlier paper.[1] The method herein described was developed under the sponsorship of the Aerological Service of the United States Navy Department with the object of providing a new approach toward meeting the rigid operating requirements faced. In the latter stages of the development, considerable co-operation was had with Julien P. Friez & Sons, Baltimore, Md.

Paper 40-47, recommended by the AIEE committee on communication, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 8, 1939; made available for preprinting December 21, 1939; released for final publication February 16, 1940.

Harry Diamond, Wilbur S. Hinman, Jr., Francis W. Dunmore, and Evan G. Lapham are all affiliated with the National Bureau of Standards, Washington, D. C.

1. For all numbered references, see list at end of paper.

The instrument requirements are rather severe. Measurements of pressure, temperature, and humidity are desired to heights of up to 25 kilometers. In such excursions, the range of pressures encountered may be from 1,070 millibars at the surface to 25 millibars at the top, the range of temperatures from +40 to −90 degrees centigrade, and the range of humidities from 0 to 100 per cent relative humidity. The required accuracies of measurement are ±5 millibars throughout the range of pressures, ±0.75 degree centigrade at temperatures above −50 degrees, and ±5 per cent relative humidity at temperatures above −20 degrees.

Superposed on the instrument requirements are practical requirements which increased materially the difficulty of the problem. Considerations of economy dictate that the unit cost of the radio sonde must not exceed the amount hitherto expended for an airplane sounding ($25 to $30) despite the facts that airplane soundings were generally limited to heights below 6 kilometers and that their regularity of operation was frequently interrupted by adverse weather conditions. The weight of the instrument must be kept sufficiently low (of the order of one kilogram) to allow its being carried to the desired height by a balloon of the dimensions given. However, a rugged construction is essential since the instrument must be capable of shipment by ordinary transportation to considerable distances and of storage for several months under field conditions without upsetting the original calibrations. Ease of handling by field personnel and minimum time requirements for making the sounding and for evaluating the observations are additional conditions.

From these considerations, it will be apparent that the practicability of a radiosonde design depends not only on its potential accuracy of measurement but also upon the ruggedness of the component elements required and upon the possibility of their manufacture by mass-production methods. The equipment to be described complies with the requirements outlined largely because of the special arrangement devised for carrying out the measurements and for translating them into signals which may be evaluated at the ground station.

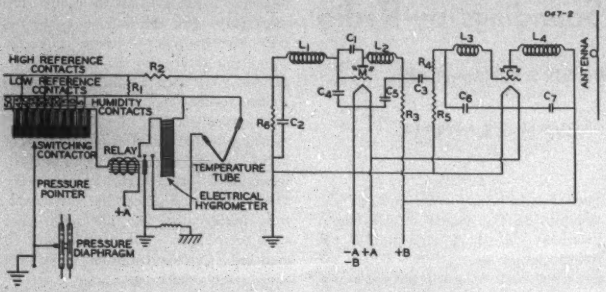


**Figure 2. Electrical circuit arrangement of the radio sonde**

$R_1$, $R_4$—1,000 ohms
$R_2$—40,000 ohms
$R_3$—25,000 ohms
$R_5$—5,000 ohms
$R_6$—1,000,000 ohms
$C_1$, $C_4$, $C_7$—0.00025 microfarad
$C_2$—0.07 microfarad
$C_3$—0.05 microfarad
$C_5$—0.01 microfarad
$C_6$—0.0001 microfarad
*M*—Modulating oscillator
*C*—Carrier oscillator

## II. Technical Features of the Radio Sonde

The principles underlying the operation of the radio sonde will be understood from a study of the electrical circuit diagram shown in figure 2. As already stated, the radio sonde consists of a radio transmitter and elements for measuring pressure, temperature, and humidity. A photograph of the radio transmitter is shown at *b* in figure 3, while the pressure-measuring unit is shown at *a*. Figure 4*a* shows the temperature element and figure 4*b* the humidity element (comprising three interconnected units). The temperature and humidity elements are fastened to opposite sides of a mounting plate which fits into a ventilated compartment of the radio-sonde container. As will be shown, these elements constitute electrical resistors which vary respectively in accordance with the temperature and relative humidity of the air to which they are exposed.

### 1. The Radio-Sonde Transmitter

Referring to figure 2, the transmitter employs a conventional receiving-type vacuum tube having two sets of triode elements in a single glass envelope. One of the triodes is connected in a carrier oscillator circuit, operating at a frequency of 65 megacycles per second and feeding a half-wave doublet transmitting antenna. The second triode is used in an auxiliary oscillatory circuit, oscillating at about one megacycle per second and having in its grid circuit a resistance-capacitance network which operates to interrupt or "block" the oscillator at a rate inversely proportional to the time constant of this network. The capacitance is of fixed value but the resistance varies so that the "blocking" frequency ranges from 10 to 200 cycles per second. This frequency is made to modulate the carrier oscillator, resulting in an emitted carrier wave having a variable audio-frequency modulation.

The one-megacycle oscillations of the modulating oscillator (controlled by the coils $L_1$ and $L_2$ and by the capacitors $C_1$

**Figure 3. The radio-sonde transmitter and pressure-switching unit**

(*a*) (*b*)

and $C_4$) are used only for triggering purposes. During the oscillating condition, the grid swings positively each half-cycle and a current flows through the resistance-capacitance network formed by the capacitor $C_3$ in parallel with the series circuit comprising $R_3$, $R_1$, and either the temperature or the humidity resistor. (The shunt resistor $R_4$ sets an upper limit to the value which may be attained by the resistance in parallel with $C_3$.) The voltage developed across this network is applied as a negative biasing voltage on the grid. The magnitude of this biasing voltage is a function of the charging rate of the capacitor $C_3$ through the tube grid-filament resistance and of the amplitude of oscillation; it builds up within about 0.5 millisecond to a value sufficient to block the oscillator. During the nonoscillating condition, the capacitor $C_3$ discharges through the resistance combination until the negative biasing voltage is again sufficiently low to allow the tube to oscillate. This action is repeated cyclically at a rate which depends upon the time-constant of the resistance-capacitance network, which, as is evident, controls only the duration of the nonoscillating period.

In the absence of the modulating oscillator, the carrier oscillator would operate continuously. However, when the modulating oscillator begins to oscillate, its plate begins to draw current and a negative pulse is applied (through the coupling capacitor $C_4$) across the resistor

**Figure 4. The temperature and humidity measuring elements**

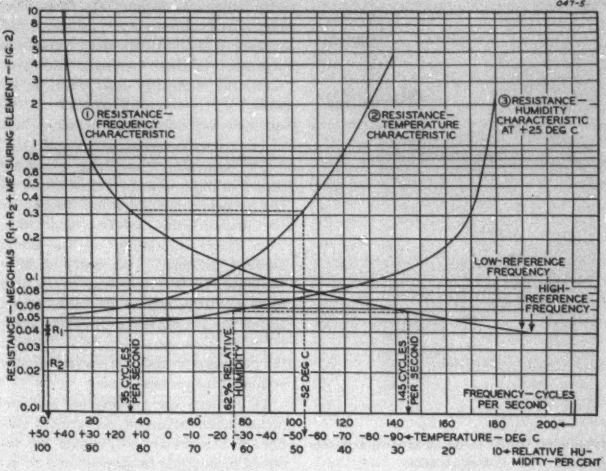


**Figure 5. Curves illustrating the principles involved in the measurement of temperature and humidity**

$R_3$ in the grid circuit of the carrier oscillator. This voltage is of sufficient magnitude to block the carrier oscillator; the carrier-frequency oscillations do not begin again until the modulating oscillator ceases to draw plate current (because of cessation of its oscillations) so that a positive pulse is applied to $R_3$. It will be evident from the foregoing that the carrier wave sent out by the radio-sonde transmitter is interrupted for short periods of constant time duration, the rate of occurrence or frequency of these interruptions being controlled by the value of the resistance in the resistance-capacitance network.

## 2. The Pressure-Switching Unit

This unit performs two functions, one as a measuring instrument of barometric pressure in the specified range, the other as a switch which connects into the resistance-capacitance circuit of the modulating oscillator, the temperature and humidity resistors and two fixed values of resistance known as the low and high reference. (See figures 2 and 3.) The pressure arm carries a tapered contact which bears against the polished face of a switching element at a position controlled by the ambient pressure. As the balloon rises into lower levels of pressure, the diaphragm expands laterally thereby sweeping the contactor over the face of the switching element and making the desired connections.

The switching element consists of 80 metallic strips separated by insulating strips. The conducting strips are arranged in groups of four adjacent intermediate contacts, the adjacent groups being separated by wider index contacts. The intermediate conducting strips are all connected together and to the field coil of a miniature relay which is energized upon completion of a low-voltage circuit by contact of the pressure-arm contactor with any of the intermediate conducting strips. The grounded armature of the relay normally rests against its back contact to which is connected one side of the temperature resistor. When the coil of the relay is energized, its armature bears against a front contact to which is connected one side of the humidity resistor.

By reference to figure 2, it will be evident that the relay operates to connect into the resistance-capacitance network of the modulating oscillator (in series with $R_3$ and $R_1$) either the resistance thermometer or the resistance hygrometer, depending upon whether the pressure-arm contactor bears against an insulating strip or an intermediate conducting strip of the switching element. The intermediate conducting strips are more conveniently referred to as humidity contacts since the time constant of the resistance-capacitance network and, hence, the modulating frequency of the radio-sonde transmitter is controlled by the resistance hygrometer when the pressure-arm contactor bears against any one of these contacts.

**Figure 6. Radio-sonde component elements in their container**

The index conducting strips of the switching element are arranged in two groups; the members of one group being connected electrically to the junction of resistors $R_3$ and $R_1$, and the members of the second group to the junction of $R_1$ with the two measuring elements. Contacts of the first group, comprising contact numbers 15, 30, 45, 60, and 75, are termed the high reference contacts, since only one resistor $R_3$ remains in circuit when the pressure-arm contactor bears against one of these contacts and, hence, a fixed high reference modulating frequency is obtained. Contacts of the second group, comprising contact numbers 5, 10, 20, 25, 35, 40, 50, 55, 65, 70, and 80, are termed the low reference contacts, $R_3$ and $R_1$ being in circuit when the contactor bears against one of these contacts and a somewhat lower fixed reference modulating frequency being then obtained.

### 3. The Measuring System

The method employed for measuring and indicating at a remote point the values of the pressure, temperature, and humidity encountered by the radio sonde during the ascent of the balloon is now evident. The radio-sonde transmitter emits a radio wave modulated by audio frequencies which correspond successively to temperature and humidity observations. The temperature observations occur when the pressure-arm contactor passes over an insulating strip while the humidity observations are obtained when the contactor bears against a humidity contact. The changeover from temperature frequencies to humidity frequencies occurs as the pressure-arm contactor just reaches a humidity contact. When the contactor reaches successive fifth contacts, the humidity observation is replaced by one of two fixed reference frequencies depending on whether a high or low reference contact is reached.

The sequence of switching operations serves as indication, by actual count, of the particular contact being reached by the pressure-arm contactor and, thus, from prior calibration, of the actual ambient pressure. This count is much facilitated by the occurrence of the high reference frequency every 15th contact and of the low reference frequency at intervening fifth contacts. In this usage, the reference frequencies serve as index points on the pressure scale.

To evaluate the temperature and humidity observations at the ground station, it is necessary to measure the received modulating frequencies and to interpret the measurements in terms of the resistance-frequency characteristic of the radio-sonde transmitter and the resistance-temperature and resistance-humidity characteristic of the temperature and humidity elements in the radio sonde. Fortunately, for this method of measurement, it is readily possible to control the manufacture of the three elements involved (the transmitter, the temperature tube, and the electrical hygrometer) so as to attain substantially uniform characteristics. Thus, the necessity for individual calibration of the three component elements is obviated and standard charts and scales may be used in evaluating the observations at the receiving station.

The principles involved in the measurement of temperature and humidity are illustrated in figure 5. Here curve 1 is the resistance-frequency characteristic of the modulating oscillator, curve 2 is the resistance-temperature characteristic of the temperature tube, and curve 3 is the resistance-humidity characteristic of the electrical hygrometer. In later sections of this paper, it will be shown that the measurements are actually made on the basis of relative frequencies rather than on an absolute frequency basis as might be inferred from the foregoing explanation. In this way, rather large tolerances may be allowed in the manufacture of the radio-sonde transmitter without affecting the accuracy of the measurements.

### 4. The Temperature Element

This device, shown in figure 4, utilizes the effect of temperature on the conduction of electricity through an electrolyte. Its construction is quite simple, as will appear from the following.

The glass capillary tube has an over-all length of 5 centimeters, a bore diameter of 0.875 millimeter, and a wall thickness of 0.4 millimeter. Capillary lengths of the required bore are purchased to a tolerance of ten per cent and, by volumetric measurements, their lengths are adjusted so as to produce an electrical resistance of 14,000 ohms (plus or minus five per cent) when filled with a standard electrolyte at +30 degrees centigrade. The capillary tubes are then bent into V form and are furnished with two glass

**Figure 7. Ground-station receiving and recording equipment**

bulbs fused to the ends. The wells provide for low-resistance contact between the electrolyte and the copper terminals of the tube, which extend through organic seals. One of the terminals consists of a very fine copper tube through which the capillary tube is filled in a vacuum chamber; the end of this copper tube is soldered to complete sealing of the device.

The standard electrolyte used consists of a solution of 24 per cent (by volume) concentrated hydrochloric acid, 76 per cent of ethyl alcohol, and 2.7 grams of cuprous chloride for each 100 cubic centimeters of the resultant mixture. The alcohol lowers the freezing point of the electrolyte to below −100 degrees centigrade, while raising the resistivity to the desired value. The cuprous chloride operates in combination with the copper terminals to eliminate polarizing action in the tube when passing direct current.[2]

The resistance-temperature characteristic of the tube is shown by curve 2 in figure 5. Provided that excessive direct current is not passed through the tube,

its calibration remains constant within 0.5 per cent for a period of a year or more.

Advantages of the device for radiosonde application include: uniformity of calibration for all tubes filled with the standard solution, large area of exposure to the ambient temperature, rapidity of response to temperature changes, and thermal isolation from other parts of the radio sonde with consequent reduction of errors in measurement due to heat conduction to a negligible order.

### 5. The Electrical Hygrometer

This device,[3] shown in figure 4, utilizes the effect of moisture on the conductivity of a hygroscopic salt. Three units are required to give the desired variation of resistance with relative humidity. The units are mounted on the opposite side of the mounting plate from the temperature tube and rain shields are provided to prevent direct contact with rain. Each unit consists of a dual winding of number 38 American wire gauge bare palladium wire (25 turns each with a pitch of 8 double turns per centimeter) wound on a coil form one centimeter in diameter. The coil form consists of an aluminum tube having a wall thickness of 0.25 millimeter and covered with an insulating coating (0.25 millimeter thick) which is highly resistant to water. After winding, the three units are each coated with different predetermined solutions of lithium chloride in polyvinyl acetate.

The surface-leakage resistance between the two interspaced windings of each unit varies with relative humidity according to predetermined characteristics. The most sensitive coating (3 per cent lithium chloride) covers the humidity range from 10 to 35 per cent; the next sensitive coating (2 per cent lithium chloride) covers the humidity range from 25 to 50 per cent; while the least sensitive coating (1 per cent lithium chloride) covers the humidity range from 40 to 100 per cent. By connecting the three units in parallel (with suitable resistors in series with the 2 per cent and 3 per cent units), the resistance-humidity characteristic shown by curve 3 of figure 5 is obtained.

This characteristic holds only at room temperature, the range of variation of resistance being modified as the temperature decreases. This results in a progressively narrower range of humidity indication at the lower temperatures; the range at −60 degrees centigrade is from 100 to about 35 per cent relative humidity.

The electrical hygrometer has important advantages over other forms of hygrometers, particularly for radio-sonde application. In an earlier form of the radio sonde described in this paper, a variable resistor controlled by the more conventional hair hygrometer is used for measuring relative humidity. While useful observations are obtained, there are two limitations to this type. The first is that the hair hygrometer does not function efficiently at temperatures below about zero degrees centigrade; the second, that even at higher temperatures it does not respond sufficiently to the sharp changes in humidity encountered by a balloon ascending at the lowest practical rate (175 meters per minute). The electrical hygrometer overcomes both of these defects. It is characterized by a very rapid response to humidity variations at temperatures down to at least −60 degrees centigrade. Its rate of response is sufficient to permit any practical balloon ascension rate, as has been determined in actual tests at ascension rates of up to 400 meters per minute.

### 6. The Complete Radio Sonde

A photograph of the complete radio-sonde assembly is shown in figure 6. A light cardboard case, covered with a metallic foil and divided into two compartments, is employed. The front compartment houses the radio transmitter *a*, the plug-in battery power supply *b*, the pressure-switching unit *c*, and the miniature relay *d*. The rear compartment supports the radiation shield *e*, for protecting the temperature and humidity elements from heating by solar radiation. The shield consists of two thin concentric aluminum tubes, the inner one of which supports the mounting plate on which the temperature and humidity elements are fastened. The shield normally extends about two centimeters above its compartment and the top edge of the mounting plate is normally flush with the top edge of the shield. The temperature and humidity elements are ventilated by the flow of air through this shield produced by the upward movement of the balloon.

The complete instrument weighs slightly less than one kilogram and its present unit price in quantities of several thousand is $27. An interesting feature of the instrument is that, with the radiation shield assembly slid down into its cardboard container, top and bottom flaps (tied back during the ascent) may be used for closing off this container. The instrument is then in convenient form for shipping or for return through the mail upon its recovery. Complete mailing instructions and the reward offered for its return are printed on the foil cover.

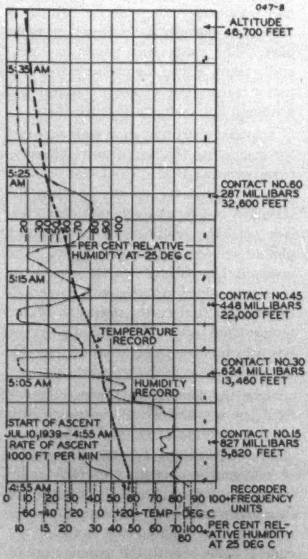
047-8
ALTITUDE 48,700 FEET
5:35 AM
5:25 AM
CONTACT NO.60 287 MILLIBARS 32,600 FEET
PER CENT RELATIVE HUMIDITY AT -25 DEG C
5:15 AM
CONTACT NO.45 448 MILLIBARS 22,000 FEET
TEMPERATURE RECORD
CONTACT NO.30 624 MILLIBARS 13,460 FEET
5:05 AM
HUMIDITY RECORD
START OF ASCENT JUL 10,1939- 4:55 AM
RATE OF ASCENT 1000 FT PER MIN
CONTACT NO.15 827 MILLIBARS 5,620 FEET
4:55 AM
RECORDER FREQUENCY UNITS
-60 -40 -20 0 +20 TEMP DEG C
PER CENT RELATIVE HUMIDITY AT 25 DEG C

**Figure 8. Record of a typical sounding**

## III. Ground-Station Equipment

Typical ground-station receiving and recording equipment are shown in figure 7. The receiving set *a* feeds an electronic frequency meter *b* which measures the frequency of the modulating signal from the balloon and converts it into a direct current proportional to the frequency. This is indicated by a microammeter on the electronic frequency meter and is simultaneously recorded by a recording microammeter *c*.

An important operating feature of the electronic frequency meter is that the current is directly proportional to the frequency within very narrow limits. Moreover, a control in the output circuit allows adjustment of the current corresponding to any frequency within the range by up to ±15 per cent without upsetting the linear relationship between the current and frequency throughout the range. The use made of this property is an essential feature in the use of the radio-sonde system described, as will appear later.

## IV. Record of a Typical Sounding

A record of a typical sounding, redrawn for reproduction, is shown in figure 8. The start of the record, corresponding to

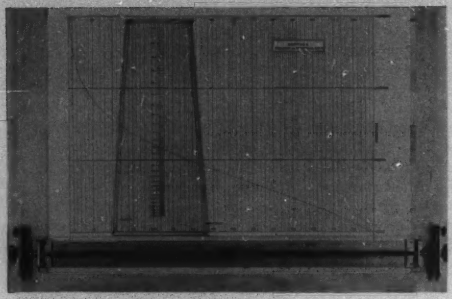

Figure 9. Illustrating the method of correlating the standard radio-sonde resistance-frequency characteristic with the standard resistance-temperature characteristic of the temperature tube

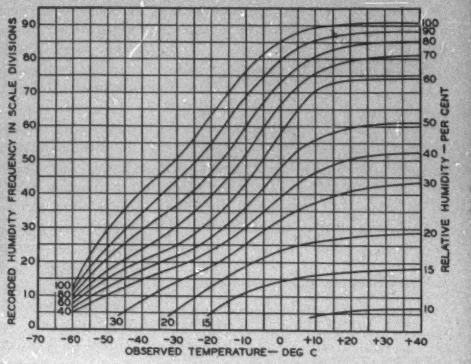


Figure 10. Charts for evaluating the relative humidity from the observed recorder frequency and the temperature at which the observation is made

the release of the balloon, is at the bottom of the chart. The recorder chart has 100 equally spaced divisions corresponding to a full-scale range of 200 cycles per second; however, it is more convenient for station personnel to work in terms of the recorder divisions which may be considered as arbitrary frequency units. For an approximate interpretation of the record, a scale of temperatures (for an average temperature bulb) and scales of humidities (at two ambient temperatures) are marked on the chart.

The traces at the extreme right of the chart represent the high reference frequencies while the traces just to the left of these represent the low reference frequencies. The physical positions of the pressure-arm contactor as these marks were being traced by the recorder may be visualized by referring to the contact numbers shown at the lower edges of the high-reference traces. (See also figures 2 and 3). The altitude of the balloon corresponding to each high-reference trace is marked on the chart as of likely interest to the reader. Altitude is determined from the air density computed on the basis of the pressure, temperature, and humidity observations.

The temperature and humidity traces are seen to form broken lines which plot, respectively, the variation of these two meteorological factors as a function of the balloon altitude. The temperature traces are readily distinguishable from the humidity traces by the nature of their variation. Each interruption of the temperature plot designates that the pressure-arm contactor has just reached a humidity or reference contact; each interruption of the humidity plot indicates that the contactor has just left a humidity contact. Light dotted lines have been added between adjacent humidity traces to emphasize the sharp variations obtained.

## 1. Evaluation of Pressure, Temperature, and Humidity

In determining the exact pressure level at which a given temperature or humidity trace obtains, the aerologist refers to the calibration chart for the particular pressure unit used. In this chart, heavy horizontal lines represent the reference contacts on the switching element and lighter horizontal lines represent the humidity contacts. The line thickness and spacing between lines are proportioned to correspond respectively to the widths of the conducting and insulating strips comprising the switching element. The ordinate scale thus represents contact numbers; the scale of abscissas represents barometric pressure in millibars. The calibrating points are generally taken just as the pressure-arm contactor reaches the reference contacts and a smooth line is drawn through them.

A special chart and glass scale are used for evaluating the temperature observations corresponding to particular recorder traces. The curve on the chart is the standard resistance-frequency characteristic of the radio-sonde transmitter plotted on semilogarithmic paper. The ordinate (logarithmic) scale represents resistance added in series with $R_2$ and $R_1$ in figure 2; that is, the resistance of the temperature tube. The scale of abscissas is in arbitrary frequency units corresponding to divisions on the recorder chart.

Since the temperature tube follows a fixed law of variation of resistance with temperature, the curve on the chart may also be considered to represent a plot of temperature versus generated audio frequency for a standard temperature tube and transmitter. However, in order to reduce the requirements as to the accuracy of the bore in the manufacture of the temperature tubes, the resistances of different tubes at a given temperature may differ appreciably even though they have the same temperature coefficient of resistance. This, in effect, requires that the temperature ordinate scale be permitted to slide up or down along the resistance scale. The required condition is met by mounting the chart on a drawing board and providing a glass plate bearing a vertical index line graduated in degrees centigrade which moves up or down on the chart. See figure 9.

The chart and scale together form a plot of temperature versus frequency, with means for sliding the temperature scale of ordinates to fit individual tubes. The lower edge of the glass scale rests against a movable horizontal crossbar (fastened to the drawing board) which facilitates making the adjustment.

Just prior to the release of a radio sonde, the operator measures the true temperature at the ground surface and the corresponding frequency observation from the radio sonde. These data are used in setting up the glass-plate temperature scale on the standard resistance-frequency characteristic. The operator moves the glass plate horizontally on the frequency chart so that the vertical index line coincides with the frequency corresponding to the observed recorder trace and then slides the crossbar on the drawing board upward or downward until the observed surface temperature intersects the resistance-frequency characteristic.

The chart used for evaluating the humidity observations is shown in figure 10. The ordinate scale is in arbitrary frequency units corresponding to divisions on the recorder chart. The scale of ab-

scissas represents the temperature at which the humidity measurements are made. The graphs represent curves of equal relative humidity. Knowing the frequency of the observed humidity trace and the corresponding observed ambient temperature, the relative humidity is determined by interpolation on the chart. Reasonable control of the manufacturing processes makes it possible to obtain electrical hygrometers which conform very closely to the standard characteristics of figure 10, within plus or minus three per cent relative humidity.

## V. Accuracy of the Observations

### 1. Analytical Considerations

It will be evident that the accuracy of the pressure observations of sounding will depend practically entirely on the accuracy of repetition of performance of the pressure diaphragm and pressure-arm linkage. Repeated calibrations of individual units show agreement of the calibration points within two millibars. A control for moving the switching element laterally with respect to the pressure-arm contactor provides for setting the unit to read correctly at the surface pressure prior to an ascent, thereby correcting for zero shift and at the same time applying a surface correction for temperature effect at ground-level pressure. The over-all temperature effect in service use is within three millibars.

The accuracy of the temperature and humidity observations depends on a number of factors which at first hand would appear to require considerable control of the component elements employed in the radio sonde and at the ground station in order to secure the required accuracy. However, simple expedients operate to reduce the tolerances to practicable values.

One expedient is to make the measurements in terms of relative rather than absolute frequency. For this purpose, the low reference frequency, having a nominal value of 190 cycles per second (95 recorder divisions), is used as a control point. From the discussion in connection with figure 2, it is apparent that the measurement of audio frequency is made merely as a convenient way of measuring the ratio of the resistance of the temperature or humidity elements to the resistance of the low reference resistor. The parameters of the vacuum tube and of the modulating oscillator circuit and the variation of these parameters even for the wide variations of plate and filament voltages and ambient temperature encountered during a sounding have but little effect upon the ratio of any two frequencies corresponding to two values of the resistance network. Similarly variations in $C_2$ have negligible effect upon such ratios. It is obvious then, that if the value of $(R_3+R_1)$ is maintained within $\pm 0.5$ per cent under operating conditions and the current control in the output of the electronic frequency meter (in the ground-station equipment) is adjusted so that the recorder reads 95 divisions whenever the low reference signal is received, the observed frequencies corresponding to particular resistance values of the temperature- and humidity-measuring elements must have predetermined relationships to the low reference frequency. This is equivalent to saying that all radio-sonde transmitters may be made to have practically identical resistance-frequency characteristics whether in the laboratory or during an ascent merely by close control of $(R_3+R_1)$. (The resistor $R_4$ being much higher than the other resistors, needs be controlled only within plus or minus five per cent.)

Thus, if the absolute reference frequency of a particular transmitter happens to be considerably different from the nominal value, the operator merely adjusts the frequency-meter control to make it read the standard nominal value. The same is true if the reference frequency drifts during a sounding. The small step variations in several of the low-reference traces on the record of figure 8 show where such adjustments were made.

Such small departures from the average characteristic as are found to occur in individual transmitters (after the reference-frequency adjustment is made) invariably take the form of a practically parallel shift of the curve upward or downward. The method of setting up the temperature scale on the basis of the surface-temperature data (described in a previous section) takes care of these departures in so far as the temperature measurements are concerned. A little consideration will show that, with this method, not only is the actual resistance of the temperature tube at the surface temperature taken into account, but a correction is automatically applied for the parallel departure of the actual resistance-frequency characteristic from the standard characteristic. While this correction does not apply to the humidity measurements, the requirements of accuracy of the humidity measurements do not demand such refinements.

Let us now consider what requirements must be met by the electronic frequency meter and the recorder in the ground-station equipment. The essential requirement is that the output current of the electronic frequency as indicated on the recorder trace shall be substantially linearly proportional to the received signal frequency and shall repeat this relationship within $\pm 0.3$ division under all conditions of operation. This condition must be fulfilled regardless of the actual value of the reference frequency and represents a maximum error in temperature measurement of 0.5 degree centigrade at zero degrees centigrade. Small deviations from the required linear relationship may be taken care of by applying a suitable correction factor to the standard resistance-frequency characteristic used with a given ground-station setup or, even if neglected, is largely corrected for (in temperature measurements) by the process of setting up the temperature scale just described in connection with the surface-temperature check.

On the basis of the foregoing discussion, it is apparent that temperature measurements to an accuracy of $\pm 0.75$ degree centigrade can be made with the radio-sonde system without placing undue manufacturing and calibration restrictions on either the radio sonde or the ground-station equipment.

### 2. Experimental Results

The curves of figure 11 provide experimental corroboration of the foregoing conclusion.[4] Curve 2 summarizes the results of 25 nearly simultaneous radio and airplane soundings. Some 100 such simultaneous ascents were made with practically the same order of agreement. The abscissas represent deviations be-

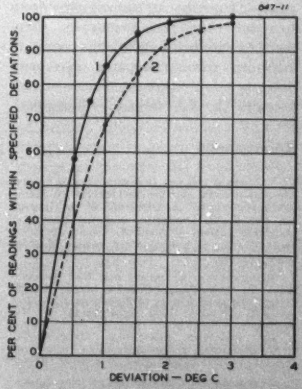


**Figure 11. Summary of comparative data obtained: (1) with simultaneous radio-sonde and balloon meteorological soundings; (2) with simultaneous radio-sonde and airplane soundings**

tween the two types of observations while the ordinates represent the percentages of the total observations falling within the specified deviations. In considering the results, it should be noted that the deviations include the effect of errors in the airplane instrument as well as in the radio sondes. Also, since the pressure measurements within the two types of instruments were required in computing altitude in order that the temperature observations might be compared at equivalent altitudes, the deviations include the effect of possible errors in the observations of pressure.

Curve 1 summarizes similar results for 20 soundings in which the balloon carried a recording meteorograph in addition to the radio sonde; the data from this recording instrument were obtained only after recovery. The better agreement shown by curve 1 is attributed to the fact that both instruments were tied together whereas, in the case of curve 2, the balloon was often carried away by winds up to 50 miles from the airplane at the upper levels.

In curve 1 temperature comparisons down to about −50 degrees centigrade are averaged, while in curve 2 the comparisons include data down to −30 degrees centigrade.

Similar data for the accuracy of measurement with the electrical hygrometer cannot be presented because of the lack of a standard for comparison. As nearly as can be determined on the basis of checks against a psychrometer in a controlled chamber, the electrical hygrometers agree within about three per cent relative humidity at temperatures down to about −15 degrees centigrade. Comparisons with hair hygrometers carried in airplanes show reasonable agreement down to temperatures at which the hair becomes sluggish (about −5 degrees).

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# Lightning Protection of Wood-Pole Lines


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**Synopsis:** The reliability of wood-pole transmission lines during the lightning season has long been a problem with operating companies. To meet the ever increasing service demands approximately 60 miles of line were reconstructed using the inherent insulation of a wood-pole line with lightning protector tubes on one of three conductors. Two years' experience with this type of construction has shown better than a 90 per cent reduction in lightning outages.


A REVIEW of the past nine years' performance on the 26-kv wood-pole lines of the Public Service Electric and Gas Company indicated that approximately 79 per cent of all interruptions were caused by lightning which represented about 38 lightning tripouts per 100 miles of line per year. This compared to a rate of 3.1 for 132-kv steel-tower lines.

After unsuccessful attempts to improve the lightning performance of wood-pole lines by the use of ground wires or wood insulation, lightning protector tubes were installed on a single-circuit 26-kv line. This line is part of a three-phase system with the neutral grounded through a 75-ohm resistor which limits the single-phase-to-ground fault currents to somewhere between 200 to 500 amperes. Since the three-phase short-circuit currents are as high as 10,000 amperes it was impossible to meet the range of currents between single-phase and three-phase faults with a single tube and a four-tube scheme would be necessary.[1] In order to reduce the cost, tubes were selected having a 60-cycle current rating of 200–1,000 amperes.

In the absence of any records at the time it was thought that the number of phase-to-phase operations would be very small. Experience showed that many of the lightning strokes involved more than one phase, resulting in the failure of a number of tubes due to the high phase-to-phase short-circuit currents. Although the number of outages was not decreased with this scheme there was very little damage to any of the transmission-line equipment and the time of outage was decreased materially.

This three-phase installation was tried for two seasons with no reduction in the number of lightning outages. In 1937 the line was rebuilt to make one phase a shielding conductor by locating it so that the remaining phases would be shielded from direct strokes. Lightning currents were drained from the shielding conductor by means of lightning protector tubes. The remaining phases were isolated from the shielding conductor and tube ground circuit by insulation sufficient to prevent phase-to-phase faults. This allowed the use of a single tube designed to withstand only phase-to-ground currents which were much less than phase-to-phase currents.

The performance of this line during the 1937 lightning season indicated that the method of protection was satisfactory but that the tubes used (15,000 to 30,000-ampere impulse current rating) would not withstand the lightning currents encountered. This conclusion was based upon the large number of tubes that failed on single-phase line outages with no phase-to-phase currents involved.

In 1938 new tubes of a greater lightning-current rating (190,000 amperes) were installed. In addition, two more lines were rebuilt to the same type of construction, making a total of 18.9 cir-

**Table I. Wood-Pole Lightning-Protection Performance**

| | 1938 | 1939 |
|---|---|---|
| Miles of line (circuit) | 18.9 | 59.4 |
| Number of tubes installed | 341 | 830 |
| Tripouts | 1 | 0 |
| Intermediate poles flashed | 0 | 0 |
| Shielded phases flashed | 0 | 0 |
| Tube insulator flashed | 1 | 0 |
| Tubes destroyed | 1 | 0 |
| Tubes operated but failed to protect | 1 | 0 |
| Tubes operated correctly | 103 | 108 |
| Total number of tubes operated | 105 | 108 |


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1. For all numbered references, see list at end of paper.

cuit miles. In 1939 an additional 40.5 circuit miles of line were rebuilt.

## Performance

The performance of these lines during the 1938 and 1939 lightning seasons is given in tables I and II.

Table I shows the operating record, by years, of the lines rebuilt for lightning protection. The absence of intermediate-pole and shielded-phase flashovers indicates that the method of application is very satisfactory; also the very high per cent correct tube operation shows that the current rating of the tubes as now used is apparently satisfactory.

Table II is a comparison of the lightning performance of these lines before and after lightning protection was installed.

In order to eliminate the effect of variation in lightning severity in different territories and years, table III was made up to show the comparison between standard and protected wood-pole lines. By putting the lines on a common basis the operating records for the years 1938 and 1939 are compared for unprotected and protected lines in the same territory. The comparison shows a reduction of about 80 per cent for 1938 and 100 per cent for 1939 in the number of lightning outages and time of interruption.

The construction used followed the original design[2] which showed an estimated reduction in lightning outages of approximately 75 per cent. Although two years' experience indicates a greater reduction in outages it is expected that a variation in intensity and number of storms will result in less improvement than the 100 per cent obtained this year.

**Table III. Comparison of the Lightning Performance of Protected and Unprotected 26-Kv Wood-Pole Lines in the Same Lightning Area**

| | 1938 | | 1939 | |
|---|---|---|---|---|
| | Unprotected | Protec.ed | Unprotected | Protected |
| Miles of line (circuit) | 48.7 | 18.9 | 53.3 | 59.4 |
| Lightning tripouts | 13 | 1 | 13 | 0 |
| Minutes interruption | 19 | 1 | 266 | 0 |
| Tripouts per 100 miles | 26.7 | 5.3 | 24.4 | 0 |
| Minutes interruption per 100 miles | 39 | 5.3 | 500 | 0 |
| Reduction in outages with lightning-protection construction (per cent) | | 80.3 | | 100 |
| Reduction in minutes interruption with lightning-protection construction (per cent) | | 86.4 | | 100 |

**Table II. Comparison of Transmission-Line Performance Before and After Installation of Lightning Protection**

| | Before | After | |
|---|---|---|---|
| | 1930–37 | 1938 | 1939 |
| Circuit miles | 63.3 | 18.9 | 59.4 |
| Total thunderstorm line days* | 3,180 | 150 | 215 |
| Total lightning outages | 204 | 1 | 0 |
| Tripouts per 100 miles per yr | 36.6 | 5.3 | 0 |
| Tripouts per storm line day | 0.64 | 0.0067 | 0 |
| Tripouts per storm line day per 100 miles | 1.02 | 0.035 | 0 |
| Reduction in outages per 100 miles per yr by protection (per cent) | | 85.5 | 100 |
| Reduction in outages per storm line day by protection (per cent) | | 98.9 | 100 |
| Reduction in outages per storm line day per 100 miles by protection (per cent) | | 96.6 | 100 |

* An index of storm exposure which is the sum of the number of thunderstorm days as determined for each line individually.

## Design

The design of lightning protection of low-voltage transmission lines incorporating high insulation strength and a shielding phase conductor with a lightning protector tube was presented in an earlier paper.[2] In brief, this system of protection is accomplished as follows:

1. One phase of each circuit is made a shielding conductor by locating it so that the remaining phases will be shielded from direct strokes.

2. Lightning currents are drained from the shielding conductor by means of a lightning protector tube.

3. The remaining phases are isolated from the shielding conductor and tube ground circuit by insulation sufficient to prevent phase-to-phase faults. This allows the use on each structure of a single tube designed to withstand only phase-to-ground currents which, in general, are much less than phase-to-phase currents.

## Lightning Protector Tubes

One of the advantages of this type of protection co-ordinated with the neutral-grounding impedance is that the variation in operating conditions and future system growth and its effect upon the currents to which the protector tube may be subjected may be neglected. This is not the case when protector tubes are installed on all three phases. The lines upon which these tubes were installed are a three-phase system nominally rated 26.4 kv with the neutral grounded through a 75-ohm resistor. In one network there are two neutrals operating. In many cases if the protector tubes were to be applied to all three phases it would have been necessary to use four protector tubes where three protector tubes of a high current rating are connected in star and the star point connected to ground through a protector tube of lower current rating.[1]

In addition, where the line is long or the system is extensive, the short-circuit currents of the lines may vary widely and zoning the tubes would have been necessary had they been installed on all three phases.

Since the single-phase-to-ground fault current is limited to a value of somewhere between 200 and 500 amperes, a tube was selected having a 60-cycle current rating of 200 to 1,000 amperes and an impulse discharge current rating in the order of 100,000 amperes. These tubes were used throughout the 26-kv system for all single-phase lightning protection. In order to have the tube function properly with the system under consideration the minimum internal tube gap permitted by the manufacturer was $6\frac{1}{4}$ inches.

In order further to decrease the cost of protection a simplified tube was used. It was felt that the life of protector tubes is dependent upon weathering of the fiber and erosion of the bore during operation and that expensive hardware was not warranted. For this reason a tube was designed using standard galvanized pipe fittings for hardware and a nail electrode. Five years' experience with tubes of this type has not shown any reason for a change to more expensive hardware.

Impulse tests using standard $(1\frac{1}{2}\times40$-microsecond) positive and negative waves were made on each pole top, with and without the tube electrode in place, in order to obtain volt-time breakdown curves of the pole-top assembly and tube as installed in the field. It was found that with 45-kv pin-type insulators without wood in series there was not sufficient margin between tube breakdown and insulator flashover for all points on the curves and that in some cases the curves

actually crossed. This was verified by observation when the insulator flashed over without tube breakdown. Since it was necessary in rebuilding some of the lines to increase the height of the poles with a steel extension bracket, it was not practical to insulate the tube mounting and ground from the insulator pin. It was found that a shield ring installed on the tube would lower the impulse breakdown of the tube, so that within practical limits, all points on the curves were at least ten per cent below the minimum

## Construction

An attempt was made to keep as much similarity as possible between protected and unprotected poles from both construction and appearance standpoints. It was also thought desirable to have a single-circuit pole that could be expanded to a double-circuit pole with only minor construction changes. In order to obtain the most economical construction the insulation between the shielding or struck conductor and its ground lead was coordinated with each of the shielded conductors, and to ground, for the various pole-top assemblies.

In order to conserve space in this paper photographs of the actual construction are not included. It was felt that drawings giving dimensions and other information would be far more valuable.

Figure 3 shows the assembly of a single-circuit protected pole top. It will be noted that the tube ground was brought down the pole by means of a clearance strap in order to increase the insulation between the tube ground and the unprotected phase wires which in turn increased the permissible distance between protected poles.

The unprotected pole is similar to figure 3 except that the tube, mounting bracket, and ground lead were eliminated and all grounds such as guys were attached at least two feet below the bottom crossarm.

The arrangement of the double-circuit protected pole top is shown in figure 4. Again the unprotected pole is similar except that the tubes, mounting brackets, and ground lead were eliminated with the highest guy connection two feet below the bottom arm. In addition a wooden crossarm brace was substituted for the steel brace shown on the top arm.

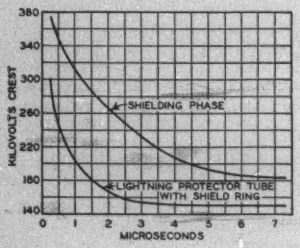


**Figure 1 (left). Volt-time breakdown curves, single-circuit protected pole, 1½x40-microsecond positive wave**

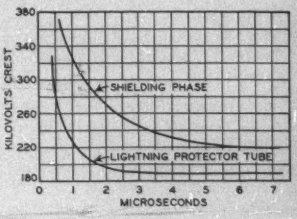


**Figure 2 (right). Volt-time breakdown curves, double-circuit protected pole, 1½x40-microsecond positive wave**

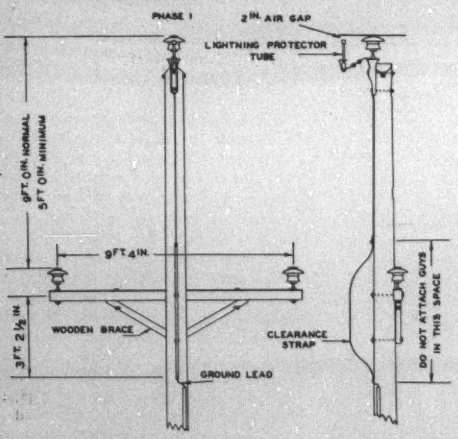


**Figure 3. Single-circuit pole top, protected pole**

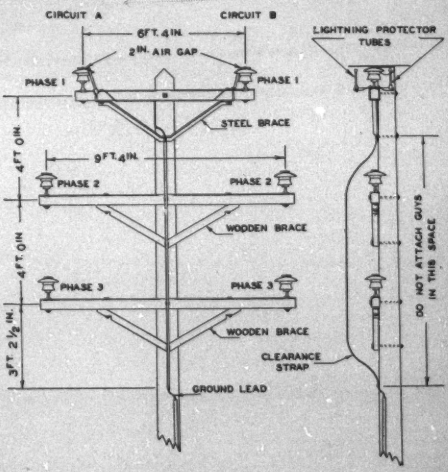


**Figure 4. Double-circuit pole top, protected pole**

breakdown values of the shielding phase. In practice shield rings were used on all tubes where the mounting was such that there was less than six inches of wood in series with the insulator and a grounded connection.

Figures 1 and 2 are typical volt-time breakdown curves of the single- and double-circuit pole tops respectively. These are composite curves made from several sets of test data and show the margin of protection between the tube and the shielding-phase breakdowns.

## Location of Protector Tubes

The duty of a lightning protector tube is, in the event of short-time overvoltages, to prevent flashover between phases and flashover to ground, other than through

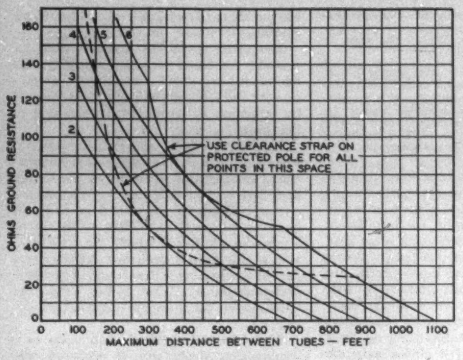


**Figure 5. Curves showing required location of lightning protector tubes, single-circuit pole line**

Numbers on curves are minimum distance in feet of guy below bottom arm on unprotected pole

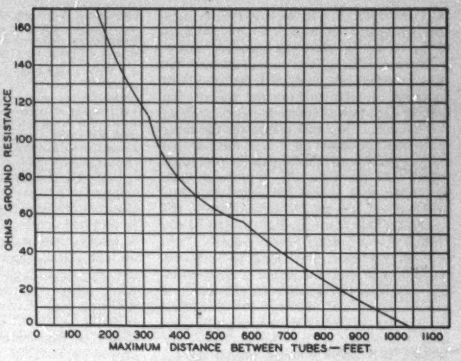


**Figure 6. Curves showing required location of lightning protector tubes, double-circuit pole line**

the tube. It must accomplish this protection on the structure upon which it is installed, called the "protected pole," and on adjacent structures called "unprotected poles."

This protection is dependent upon the insulation of the various structure assemblies, the resistance of the tube grounds, and the distance between the tube installations. These conditions were taken into account, both for the protected and unprotected poles, in determining the required location of tubes as given on the following curves.

Figure 5 is for a single-circuit line and shows the allowable distance between protected poles as dictated by the ground resistance of the tube grounds and the location of guy attachments. Since guy locations are determined by local field conditions a family of curves is included to provide for the pole in the section, between protected poles, having the least insulation to ground. As mentioned previously, the clearance strap is installed on the protected pole in order to increase the insulation between the tube ground and the protected phase wires. This strap is not always necessary as indicated by the dotted line on figure 5. For example no clearance strap is needed if the ground resistance is below 24 ohms or if there is an unprotected pole in the section which requires a guy as close as two feet below the bottom arm.

Similarly figure 6 gives data for a double-circuit line based upon the use of a clearance strap on all protected poles. Because of the protected-pole limitation there is no advantage in attaching guys on the unprotected poles more than two feet below the bottom arm.

Two years' operating experience with this type of lightning protection has confirmed the conclusions given in the paper presenting the original design.[2] At the present time it is planned to rebuild an additional 90 circuit miles in 1940 to be in operation for the coming lightning season so that further experience will be obtained.

## References

1. Protector Tubes for Power System, H. A. Peterson, W. J. Rudge, A. C. Monteith, and L. R. Ludwig. AIEE Transactions, volume 59, 1940 (May section) pages 282–92.

2. Lightning Protection for Transmission Lines, A. W. Gothberg and A. S. Brookes. Electrical Engineering (AIEE Transactions), volume 56, January 1937, pages 13–16.

## Discussion

**E. Piepho** (The Detroit Edison Company, Detroit, Mich.): The authors have presented a good case for lightning protection on wood-pole transmission lines using protector tubes on a high-shielding phase wire. However, reduction of lightning tripouts alone will not justify the expenditure for this type of protection in all cases. Other factors such as maintenance expense, the number of actual service interruptions occasioned by lightning tripouts as compared with tripouts due to other causes, duration of service interruption, etc., must be fairly evaluated. In cases where the line serves as a tie in the transmission network, its opening will not necessarily result in a service interruption and is, therefore, of small consequence if it can be immediately reclosed. Generally speaking, lightning damage does not prevent reenergizing the line within a minute or less, so that even when service interruption occurs it is of short duration. Interruptions due to wind, trees, equipment failure, or public interference, while not very frequent, are much more likely to hold the line out for a considerable time.

On The Detroit Edison Company 24-kv system the five-year operating record for 1,000 miles of overhead lines shows an average of 28.5 lightning tripouts per 100 miles per year. Of this number, 10.5 lightning tripouts per 100 miles per year caused service interruptions of five minutes or less, and only one caused a service interruption exceeding five-minutes' duration. This latter figure compares with 1.4 service interruptions exceeding five minutes due to other causes previously mentioned. It is doubtful whether tube-arrester protection can be justified for the entire system to eliminate so few service interruptions due to lightning, although in the case of a few lines the application of protector tubes appears to be a good investment. Three such lines were equipped with protector tubes in 1939, the selection having been based on line maintenance cost due to lightning, and the importance of the service supplied by the line.

In addition to this protector-tube application, tube arresters were installed on 24-kv pole-top switches in 1938. One-hundred-forty switches were selected for this protection, the selection having been determined by the past operating record of these switches with respect to lightning damage. During the 1939 storm season this protection functioned at an average rate of 1.3 times per switch protected. Only one switch suffered damage due to failure of the tube arresters. This was caused by failure of the protector tube to clear follow current due to excessive tube erosion, which may have been caused by multiple or continuing lightning strokes.

These tubes were inspected last autumn and several removed because of excessive erosion. It appears that isolated installations of protector tubes such as these result in more rapid erosion than has been reported for installations of tubes distributed along a line.

Two protector tubes were found with their bores partly plugged by mud and foreign material such as used by wasps. It is possible that such obstructions may account for the ruptured tubes reported by some users.

**H. P. Sleeper** (Public Service Electric and Gas Company, Newark, N. J.): Because of the economics involved, open-wire wood-pole transmission-line construction has constituted in the past, and probably will continue to constitute in the future, the bulk of high-power transmission systems in this country. For that reason the lightning protection of such lines has formed the subject of innumerable papers presented before this Institute. It is probably safe to predict that means for combatting this problem will continue to accumulate in the records of this Institute and the files of the United States Letters Patent Office.

It is, therefore, refreshing to review a paper which does not invent a new device but which merely applies an old one in a novel manner to secure improved operation. Such is the subject of the paper on "Lightning Protection of Wood-Pole Lines" by Messrs. Sels and Gothberg, and if the results quoted are any indication of the expected performance, it would seem that the operating results should be meritorious and the economics very favorable.

A study was made by this discusser in connection with the transmission system described by the authors to determine whether the scheme described in this paper, or a Petersen coil, should be applied to improve operation. A study of faults was made from oscillographic data obtained over a considerable period of years. The type of transmission construction involved consisted of a triangular arrangement of phases with two phase wires on top and a 36-inch spacing.

Obviously this construction favored the occurrence of short circuits due to lightning. The cable portion of the complete transmission system constituted 30 per cent of the total mileage. Results over a five-year survey showed that 80 per cent of all faults occurred on the open wire and bus sections of the system, and 20 per cent on the cable section. Furthermore, only 21 of the 80 per cent open-wire and bus faults started to ground. As a matter of interest, 16 of the 20 per cent cable faults started to ground. Hence it was apparent that the 21 per cent of all faults was all that could be eliminated by any scheme of ground-fault extinction. Hence if 90 per cent correct operation were granted to either Petersen-coil operation or expulsion-tube operation, it would still leave 80 per cent plus faults to be relayed out. On this basis the installation of a Petersen coil was not considered economically justifiable. On a program of gradually rebuilding the transmission lines, however, the preferred construction as shown in the authors' paper was practically as cheap as any other and the full effect of the expulsion-tube operation could be obtained at once on the rebuilt lines. On that basis the protective-tube scheme was approved.

This scheme of open-wire transmission construction has distinct advantages:

1. All single-phase-to-ground faults should be extinguished in not more than one cycle of arcing time. In this feature it should compare directly with the operation of a Petersen coil.

2. It should not affect in any way the operation of existing protective relays on the lines. If relays are in use which will respond to short-circuit impulses of one cycle or less, as is the case on the system in question, it will be necessary to delay the tripping of the breaker for that length of time to avoid incorrect operation during the time of tube operation. A scheme for doing this was described by me in the past and is published. (See page 292, ELECTRICAL ENGINEERING, 1938.) The same is true of a Petersen-coil installation.

3. With a high-impedance system neutral in use, as the 75 ohms in the neutral of the system described by the authors, the duty on the tubes does not increase with changing generating capacity in service due to time of day or changing load growth with the years. To a certain degree only, this is also true of a Petersen-coil installation.

Probably the greatest contribution to the continuity of service to the customers of electric utilities today and in the near future is, and will continue to be, the installation of fault-extinguishing devices of some kind on high-voltage transmission lines. Today the two types which have been compared in these comments present interesting possibilities, and existing systems, and particularly systems constructed hereafter, should be capable of capitalizing on their proved capabilities. If a choice must be made as to which system to employ, a study of each individual case seems to be the only answer. If existing line construction is considered satisfactory, or if major reconstruction is not to be made, the Petersen coil will, in this commentator's opinion, prove to be the cheaper to install and maintain. However, it is this writer's opinion that serious consideration should be given to the installation of both types of protection on a given system for the following reasons:

1. The duty on the expulsion tubes would be reduced and longer life should result.

2. Smaller tubes could be used on high capacity systems because of the reduced recovery voltages.

3. Ground faults on busses would be extinguished, which is not accomplished by tubes. This should make the installation of bus differential relay protection unnecessary, except on the very most important busses, since almost all bus faults originate to ground. The economics of this possibility may be paramount.

**L. E. Merrow** (Rockland Light and Power Company, Nyack, N. Y.): The Rockland Light and Power Company, after considering protection to about 90 circuit miles of 33-kv delta transmission lines of both wood-pole and steel construction, installed a Petersen coil last spring. The territory covered by these lines is north of Public Service Electric and Gas Company, which is above the New Jersey-New York border and has about the same amount of lightning.

Since the coil was installed over 60 per cent of the line disturbances were caused by lightning and 52 per cent of these were extinguished by the action of the coil. The remainder of the disturbances causing trip-outs were either phase-to-phase or two-phase-to-ground. Since some of the wood-pole lines have flat construction, many of the phase-to-phase short circuits occurred on these lines. It is possible, however, that if these particular lines had been protected by rebuilding each pole as suggested in Mr. Sels' paper, the operation of the coil might have been more satisfactory.

**F. Von Voigtlander** (The Commonwealth and Southern Corporation, Jackson, Mich.): The authors, following the earlier paper on this subject by A. W. Gothberg and A. S. Brookes, present interesting and valuable data on the development of the idea of converting one conductor of a line into a combination phase and shielding wire.

The writer would like to ask to what extent this combined phase and shielding conductor has provided direct-stroke protection for the line such as might be evidenced by reduction in structural damage due to lightning.

The double-circuit construction shown in Figure 4 appears to employ quite conventional spacing and is similar to the design proposed in the 1937 paper. The single-circuit construction as shown in figure 3, however, places the shielding conductor at a considerable height above the other two and in this respect departs markedly from the conventional as well as from the previous proposed design. What factors led to the adoption of the present single-circuit design?

Whenever the use of the conductor as a combination shield wire is proposed, the treatment of the transpositions must be given consideration if the possibility of two-phase-to-ground faults is to be avoided. Various schemes have been proposed to meet this problem. What features have the authors incorporated in their design to take account of the presence of transpositions in the protected line?

**E. J. Allen** (General Electric Company, Pittsfield, Mass.): The paper by Messrs. Sels and Gothberg is a valuable addition to the field experience with protector tubes, particularly since it describes a substantial application of protector tubes on the top phase or phases only.

This scheme of protection is fundamentally the same as that for the overhead ground wire, since under impulse conditions the top protected phase acts as an overhead ground wire by discharging through protector tubes to ground. Hence, the same fundamental requirements apply as to adequate shielding to unprotected conductors, low ground resistance, and sufficient clearance at mid-span, which govern overhead-ground-wire practice.

Since other operating companies may wish to consider lightning protection of lines by protector tubes on top conductor only, the curves figure 1 of this discussion have been prepared to show the allowable stroke current (two microseconds to crest) through different ground resistances at the protected structure with various impulse flashover values from ground wire to shielded phase conductors. This is based upon the flashover formula[1] described in the appendix of this discussion. A coupling factor of 0.22 was used which appears to be reasonable for the cases presented by the authors, and the relatively negligible effect of normal-frequency voltage was neglected.

Table I was based on 250-foot separation of protector-tube installations, corresponding to tubes on the top phase only at every structure if the span length is 250 feet; or a tube at every other structure if 125-foot spans are used. With the 250-foot separation of protector tubes and two-microsecond lightning-current front, reflections from adjacent protected structures will reduce the voltage and if flashover to shielded phase occurs, it will occur at approximately two microseconds for a stroke between protected structures and at

2 to 3.5 microseconds for stroke to protected structure.

Figure 1 enables analysis under two conditions:

(*a*). Stroke between protected structures

(*b*). Stroke to protected structure

The curves, figure 1, show the advantage of wood crossarm braces and the clearance straps on lower phase (or phases) of protected structures to increase the impulse insulation as described in the paper. For example, for stroke to the protected structure (solid curves) with currents not over 30,000 amperes, an increase in the insulation flashover of shielded conductors from 200 to 400 kv permits ground resistances of 25 ohms instead of 10 ohms. If the flashover level is but 200 kv and ground resistance 25 ohms, the protection would be had for lightning currents up to only 15,000 amperes.

Where the advantages of protector tubes having high discharge current capabilities of 100,000 amperes are to be fully realized, both the effect of high insulation of shielded conductors and low grounding resistance must be utilized if protector tubes are applied to top phase or phases only. For example, for strokes to protected structure of 100,000 amperes, the ground resistance required to prevent flashover of 400 kv lower-phase insulation is 5.5 ohms.

The dotted curves, figure 1, show the similar relationships when a stroke occurs between protected structures. As the authors point out, where intervening unprotected structures do exist, use should be made of available wood insulation between line insulators and ground, eliminating any grounded objects at the top of the structure, as for example, guy wires or down leads to ground. For example, a structure of the type shown in figure 3 of the paper not having a protector tube or a down lead to ground would have a higher flashover voltage $V(t)$ owing to the longer flashover path from top phase to shielded phases. This voltage (dotted curves) should be used in figure 1 when considering the stroke as occurring between protected structures. Where there are no intervening unprotected structures, as for example, a protector tube at each structure, the impulse voltage to cause mid-span flashover corresponds to the air strike distance between conductors at mid-span.

In the example previously considered, where the shielded conductors of a protected structure had a line-to-ground flashover of 400 kv and a ground resistance of 25 ohms, an intervening unprotected structure without down leads may have a line-to-line flashover of 500 kv or more.

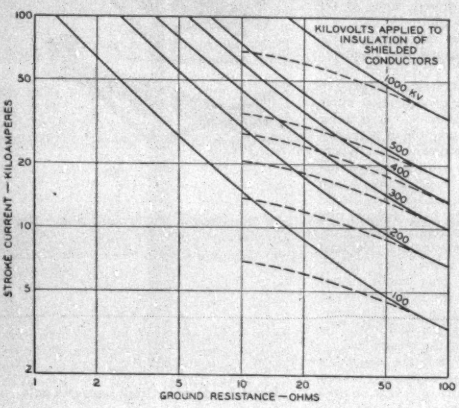


**Figure 1. Effect of stroke current upon potential applied to insulation of shielded conductors for various ground resistances of protected structure**

Two - microsecond front protected structures 250 feet apart

Solid curves—Stroke to protected structure

Dashed curves—Stroke between protected structures

If the flashover level is 500 kv, the dotted curve shows protection would be afforded the shielded conductors up to 28,500 amperes for 25-ohm ground resistance as compared to 30,000 amperes permissible stroke current to protected structure. By increasing the insulation level between protected structures, this has the advantage of making the line capable of withstanding stroke currents of the same order of magnitude at mid-span as at the protected structure.

The maximum stroke currents which can be permitted at and between protected structures, obtained from figure 1, can be referred to a curve showing frequency of occurrence of various lightning current magnitudes in service.[2] From this the percentage of strokes which the line can handle without flashover can be obtained.

In the two cases investigated, strokes between and at protected structures were considered separately and methods given for estimating them. Actually, however, the stroke may hit the line at any point. Since the nature of the problem hardly justifies a separate investigation for each point on the line where the lightning may strike, it can be assumed, on the average, any stroke within a quarter of the distance of separation between protected structures will be equivalent to a stroke at the structure with the solid curves figure 1 applying, while strokes within similar distance from a mid-point between protected structures are evaluated by the dotted curves, figure 1.

Where protector tubes are applied on all three phases, the protection afforded is independent of ground resistance, the latter values are important only in so far as they affect the single line-to-ground power follow current during tube discharge, and the selection of the minimum-current interrupting rating of the protector tube.

Table I of the paper shows in 1938, 105 operations of the 341 installed tubes were recorded, or 30.8 per cent. The tube operations were 5.7 per mile per year. In 1939, 108 operations of 830 tubes installed were recorded, or 13 per cent, corresponding to only 1.8 operations per mile per year. The total thunderstorm line days, however, had increased to 215 (1939) as compared with 150 thunderstorm line days during the preceding year. The variability between the number of operations of protective devices and the number of thunderstorm days is not unusual. It may be partially accounted for, however, if the storms experienced in 1939 were localized over a small zone of the 59.4 circuit miles of line where protector tubes were installed.

## Appendix

The flashover formula derived by Bewley is:

$$V = (1 - C_n)aR'I + e$$

in which

$V$ = voltage across the insulation

$C_n$ = coupling factor (depends upon the number, configuration, and spacing of the conductors, and is modified by corona)

$a$ = crest factor (depends upon the length of spans or the distance between protector tubes, structure footing resistance, lightning wave front, and conductor surge impedance)

$R'$ = effective resistance (depends upon the grounding resistance, and the surge impedance of the lightning stroke and of the stricken conductors)

$I$ = lightning current which the stroke could deliver to a zero-resistance ground (which is equal to twice the traveling-wave current in the stroke)

$e$ = effective instantaneous normal-frequency voltage (depends upon the normal-frequency polarities and the conductors involved)

## References

1. Protection of Transmission Lines Against Lightning: Theory and Calculations, L. V. Bewley. *G. E. Review*, April 1937, pages 180–8.

2. Lightning Investigation on Transmission Lines—VI, W. W. Lewis and C. M. Foust. Electrical Engineering (AIEE Transactions), January 1937, page 101, figure 1.

**H. N. Ekvall** (Philadelphia Electric Company, Philadelphia, Pa.): The paper by Messrs. Sels and Gothberg describes a very interesting application of protector tubes to 26-kv wood-pole lines and indicates that it has effected a reduction in line outages of 80 per cent and better. It should be noted, however, that in applying this scheme the insulation strength of the wood-pole lines was materially increased by changing to high ridge pin and twin vertical wire configurations, replacing metal with wood braces and relocating guys.

Experience on approximately 600 miles of 13- and 33-kv wood-pole lines of the Philadelphia Electric Company during the past

five years indicates that such increases in the wood insulation strength alone (without application of protector tubes) can effect large reductions in trouble. For example, on 13-kv lines, changeover from flat-top to ridge-pin configuration, relocation of guys, and use of wood braces to take better advantage of the wood-pole insulation have been largely responsible for an 89 per cent reduction in line interruptions per 100 circuit miles during the period 1935 to date. Similarly good performance has been obtained on the 33-kv lines.

The principle of protection employed by the Philadelphia Electric Company is to minimize the formation of power arcs following lightning flashover by increasing the length of wood insulation between phases and between phase and ground up to certain minimum values. This principle of protection has proved effective as indicated above. Power arcs are the chief source of trouble, while lightning itself seldom causes more than slight splintering on the pole or crossarm.

Based on the Philadelphia Electric Company operating experience, it is estimated that the protected 26-kv lines referred to in this paper would have shown a reduction in outages of the order of 80 per cent due to their increased insulation alone, with protector tubes and ground wires omitted. It appears, therefore, that much of the benefit to line performance probably comes from the increased insulation and that a small improvement may come by addition of the protector tubes.

The authors indicate that it is planned to rebuild an additional 90 miles of line in 1940 with increased insulation and protector tubes. In order further to verify the benefits of wood insulation referred to above, it is suggested that on some of the rebuilt lines the ground wires and protector tubes be omitted. This will permit a comparison of the performance of high insulation with and without protector tubes.

**Edward Beck** (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Messrs. Sels and Gothberg are to be congratulated on at least two counts. Two years ago one of the authors in collaboration with Mr. Brookes published a paper in which the use of one phase wire equipped with tubes was proposed as a ground wire for the circuit. This in itself was a departure from usual practice, and the authors are to be complimented for their initiative in risking the innovation. But further than this, they made calculations two years ago and predicted a reduction of 75 per cent in lightning outages. This was a bold statement at the time. That it was carefully considered and based on sound logic is indicated by the fact that their predictions have more than been fulfilled. We note, however, that now they are more conservative and are careful to state that they do not expect the 100 per cent record to continue. It would add to the completeness of the paper and thus to its value, if the data and premises on which the curves of figures 5 and 6 are based were reproduced also.

The first paragraph mentions about ten times as many line tripouts on the wood 26-kv as on the steel 132-kv circuits. The ground-wire protection on the 132 kv, no doubt, makes much difference. The paper illustrates that a high degree of immunity to lightning outage can be achieved either by proper ground-wire or tube application.

This paper and the one of two years ago together constitute a good example of the solution of a lightning problem by applied engineering.

**G. E. Dean** (Public Service Electric and Gas Company, Newark, N. J.): In discussion of the paper by Messrs. Sels and Gothberg, I wish to present some of the aspects of field application.

The 26-kv wood-pole transmission of the Public Service Electric and Gas Company contains many miles of single-circuit single-crossarm flat-configuration construction. In order to adapt the new configuration where one phase wire is elevated, considerable rearrangement of the pole top is necessary in addition to the relocation of guys. Where sufficient pole height is present the pole-top pin is used. With this construction, where there is no wood insulation between the insulator pin and the tube base, a shield ring is used to lower the breakdown voltage of the tube. The intermediate pole is identical but is without tube or ground wire. Where there is not sufficient pole height a steel pole extension is used and again the shield ring for the tube is required. The intermediate pole is again identical with the omission of the tube and the ground lead.

The shield ring used with tube assemblies where there is no wood insulation between the insulator pin and the tube base reduces the breakdown voltage of the $6^1/_4$-inch internal gap by redistributing the electrostatic field around the tube. The ring design is simple and rugged, consisting of three legs to support the ring; these legs in turn being welded to a large washer base. The washer of the shield ring fits over the pipe nipple at the base of the tube so that the ring assembly is slipped over the tube base and the tube installed in the normal manner.

Existing double-circuit poles are of either the two-crossarm triangular configuration or the three-crossarm vertical configuration.

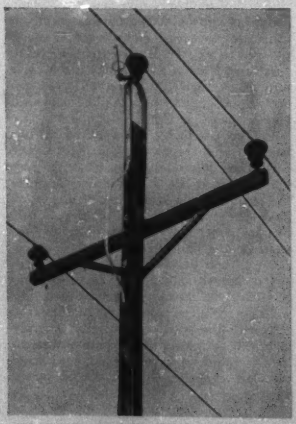

Figure 2. Single-circuit protected pole

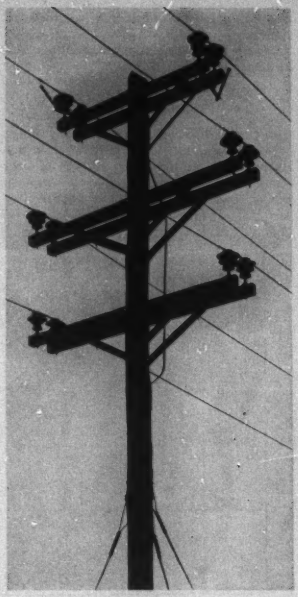

Figure 3. Double-circuit protected pole

Since the new construction is of the three-crossarm type considerable rearrangement may be required. Side guys may be attached to the end of the top crossarm when tubes are used or, in all other cases, must be well below the bottom crossarm. Either the tube or the intermediate pole may of course be double armed for strength requirements without affecting the protection. During the work of the last few years, poles of insufficient height have been replaced with a higher pole but design and test work has been completed on a joint which will permit a wood-pole section supporting one crossarm to be spliced on top of an existing pole. Much of this work will be done during the 1940 program.

Where a tube is installed on a heavy angle pole using suspension type insulators it is necessary to increase the number of insulators on the lower phase wires and attach the guys either to the top of the pole at the tube base or well below the bottom phase. Where no tubes are installed on the corner pole the number of insulators on all phases is increased and the guys must be insulated.

The simplified tube mentioned in the paper consists of the horn fiber tube, itself consisting of concentric tubes of suitable outside diameter to accommodate one-inch pipe threads and the inside, or bore diameter, slightly over one-quarter inch as determined by the 60-cycle phase-to-ground current. The internal gap length is established by choosing a nail of the proper length to give $6^1/_4$ inches between the end of the nail and the washer at the grounded end of the tube. This internal gap length is of course determined by the flashover characteristics of the insulator to be pro-

tected and the recovery-voltage characteristics of the system on which the tube is used. The base of the tube, which is grounded, consists of a straight threaded pipe nipple which is inserted in a hole punched in the mounting strap. A lock washer and nut or nut and lock nut on the nipple below the strap completes the assembly.

It is not expected that this simplified tube will have a life, when exposed to the weather, equal to that of the more elaborate designs. However, the development of the expulsion gap is far from finished and designs have changed so materially that it is not felt necessary to adopt a design of long expected life. The installation of the tubes is made in such a manner that warping of the tube cannot close the external gap and result in the burning of the tube by power current and the tripout of the circuit. It is expected that these tubes will be repainted each three years during the regularly scheduled pole-top inspection.

**H. K. Sels and A. W. Gothberg:** The authors value the discussions offered and will attempt to close the paper as briefly as possible.

Edward Beck suggests that the data and premises on which the curves of figures 5 and 6 are based should be reproduced also. To include this information would be merely a repetition of a previous paper, reference 2 of the present paper. There have been no changes in the values used as can be borne out by figure 8 in the original paper which corresponds to figures 5 and 6 of this paper. Additional curves were added to figures 5 and 6 to provide for various locations of guy attachments on the poles and also to take advantage of the additional insulation provided by the clearance strap.

The economics of lightning protection is questioned by E. Piepho. It is not suggested that all electric operating companies should rebuild all of their lines to provide this type of protection, but it is felt that if lightning is any problem at all, new lines when constructed can be built to accommodate this protection and the tubes added at any time.

Interruptions of any kind are a hard thing to evaluate. Since transmission is one cog in the electric-utility field there are many associated benefits with this type of protection, such as a reduction in the duty of terminal equipment by lessening the number of tripouts, reducing the number of dangerous overvoltages in stations and adjacent cable sections, improved customer service and its effect on system planning. In considering the necessity of any type of lightning protection the isokeraunic level must be taken into account. There is no doubt that there are some sections of this country where an expenditure for any lightning protection could not be justified. The method of protection proposed is, in the authors' opinion, the most economical to date for the benefits derived and the justification for its economic application depends upon many considerations of the operating company.

E. J. Allen presented a curve, figure 1, showing the effect of stroke current upon the potential applied to insulation of shielded conductors for various ground resistances at the protected structure, with a given distance of 250 feet between protected structures. It will be found by referring to the paper presenting the original design (reference 2) and the results given in figures 5 and 6 of this paper, that they agree very favorably. We wish to thank Mr. Bewley for the time involved to show this agreement and it was upon his original methods that some of our analysis was based and led to the prediction of a 75 per cent reduction in lightning outages.

F. Von Voigtlander has asked to what extent this combined phase and shielding conductor has provided direct-stroke protection for the line as evidenced by reduction in structural damage due to lightning. Two years' experience, with a close examination of all pole tops, has shown no structural damage, indicating 100 per cent shielding effect. As evidence that direct strokes were encountered there were many cases of consecutive tube operations along the line. Anywhere from 5 to 11 tubes have operated in a row. In one particular case in 1938 a tube rated at 100,000 amperes surge current blew up without a line tripout, indicating power current did not cause the damage. In this case all tubes operated in a section of the line for approximately 3,500 feet. Mr. Von Voigtlander also points out that the present single-circuit pole top differs from the one proposed in the 1937 paper. The only difference shown is an additional four inches vertical separation of the shielding conductor above the other two conductors for "minimum" spacing. This change is brought about by a change in pole-top bracket, otherwise the dimensions are the same. The nine feet "normal" distance is used when a single-circuit pole may be converted into a double-circuit pole and the crossarm then becomes the lower crossarm of a double-circuit pole top by the addition of two crossarms and the elimination of the ridge pin. Reference has been made to the question of transpositions but nothing has been worked out to take them into account. Fortunately, low-voltage pole lines are usually short, as is the case of the lines involved in this instance, and no transpositions exist in the lines with this protection.

L. E. Merrow's discussion of his experience with a Petersen coil indicates the necessity of providing a drain point to ground for lightning currents when a coil is used, otherwise many phase-to-phase tripouts will result. This was pointed out in a discussion by one of the authors in AIEE Transactions, volume 57, 1938 (December section) page 672.

H. N. Ekvall states that on 13-kv lines of the Philadelphia Electric Company the use of wood insulation has been largely responsible for an 89 per cent reduction in line interruptions and that similarly good performance has been obtained on the 33-kv lines. He suggests that we rebuild some of the lines and omit the protector tubes to show that the increased wood insulation will give an 80 per cent reduction in outages. There is no doubt that the rebuilding of any line by providing more clearances and newer equipment will eliminate many tripouts of all causes. We have tried the use of wood insulation only, exactly as Mr. Ekvall has suggested without the 80 per cent reduction in line outages and found by experience that a good number of the strokes were causing wood splintering. Since this was a source of later trouble wood protector blocks were used in order to direct the wood splintering to a piece of equipment that could be easily replaced. It was then found that these wood blocks would blow up and result in a power arc.

If induced strokes only are to be considered we would agree with Mr. Ekvall but since direct strokes have to be accounted for and putting performance on a basis of outages per 100 miles per year rather than per cent improvement, which depends upon what you start with, we estimate 18 tripouts or cases of damage per 100 miles per year with wood insulation only as compared to 3 tripouts per 100 miles per year with tubes. Generally speaking, we think Mr. Ekvall is getting his protection in the deionizing action of the wood as indicated by the splintering so that the economics of his applying tubes depends upon the damage he is experiencing.

In connection with Mr. Sleeper's recommendations that serious considerations should be given to the installation of a Petersen coil and tubes on the same system, it seems to the authors that the tubes on a Petersen-coil system are entirely unnecessary with protected-phase-wire construction. As pointed out previously, arcing gaps should be provided between the top phase wire and ground to drain the lightning currents from the line. The attention of the manufacturers is called to the necessity for such a device.

We wish to thank Messrs. Dean and Sleeper for their contributory discussions and all of our associates for their share in making this development a success.

# The Characteristics and Power Requirements of Spinning Frames—II

E. A. UNTERSEE
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THIS PAPER is a continuation of the investigation on the characteristics and power requirements of spinning frames presented at the AIEE North Eastern District meeting, Springfield, Mass., May 3–5, 1939, and published in this volume of AIEE TRANSACTIONS, pages 1–4 (January section).

The original investigation involved a 348-spindle Whitin frame with $1^1/_2$-, $1^3/_4$-, 2-, and $2^1/_4$-inch diameter rings operating at various speeds, and while the analysis indicated very definite characteristics and power requirements, the tests were not sufficiently extensive to conclude that the power formula developed would hold true for larger ring sizes and different-size yarns.

Further tests were therefore conducted on a 216-spindle Whitin frame, with $2^1/_4$-, $2^1/_2$-, $2^3/_4$-, and 3-inch rings spinning 10*s* yarn, and it is the analysis of these tests and their association with the previous tests that is now presented.

In comparing these recent tests with the original tests, it is immediately evident that the $2^1/_4$-inch ring is common to both and that they do not indicate the same power requirement. It is also evident that these two tests were made with different size yarns, and therefore, the formula submitted for the power requirements in the first paper cannot apply, inasmuch as it takes no account of yarn size.

The effect of yarn size on power requirements, other conditions being the same as indicated in figure 1, is definitely a factor to be considered in establishing a formula.

In figure 2, the relationship between yarn size and yarn weight is shown, and since the weight is so small and decreases so gradually in sizes smaller than 20*s*, it is doubtful whether it will affect the power appreciably in this range. In sizes larger than 20*s*, however, the weight increases rather rapidly, and should, therefore, be taken into consideration, but probably 4*s* yarn is about the largest generally made on spinning frames.

In figure 1, which covers the $1^1/_2$-, $1^3/_4$-, 2-, and $2^1/_4$-inch rings on the 348-spindle frame, and the $2^1/_4$-, $2^1/_2$-, $2^3/_4$-, and 3-inch rings on the 216-spindle frame, the power curves have all been reduced to a 216-spindle basis for the purpose of comparison, and in this comparison we have the following data to analyze for the effect of yarn size on power:

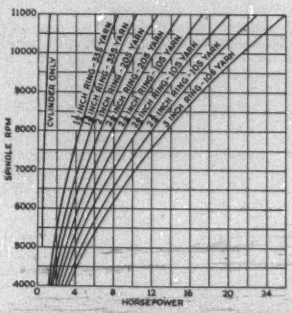


**Figure 1. Power requirements of a 216-spindle spinning frame with different diameter rings and various yarn sizes, plotted from formula derived from test data**

| Ring Diameter (Inches) | Yarn |
|---|---|
| $1^1/_2$ | 33*s* |
| $1^3/_4$ | 33*s* |
| 2 | 20*s* |
| $2^1/_4$ | 20*s* |
| $2^1/_2$ | 10*s* |
| $2^1/_4$ | 10*s* |
| $2^3/_4$ | 10*s* |
| 3 | 10*s* |

If we analyze each one of the curves separately, the power seems to vary as $(\text{rpm}/1{,}000)^{2.64}$, rpm being the spindle speed.

The spacing of these curves must depend on the ring diameter and the size of yarn, and if we consider frames on which the same size of yarn is spun and run at a fixed speed, it shows the power varies in accordance with 1.42 power of the ring diameter.

The other variable which enters the picture, namely yarn size, is evident in the power curves for the $2^1/_4$-inch rings with 10*s* and 20*s* yarn, and here the power appears to vary in accordance with

$$\frac{1}{\sqrt[4.75]{\text{yarn size}}}$$

from which we may develop the formula for power:

$$\text{Horsepower per spindle} = \frac{0.0003055}{\sqrt[4.75]{S}} \times R^{1.42} \times \left(\frac{\text{rpm}}{1{,}000}\right)^{2.64}$$

where

$S$ = yarn size
$R$ = ring diameter in inches
rpm = spindle speed

Table II has been calculated using this formula. Ring sizes and yarn num-

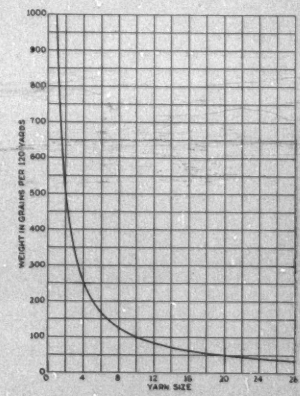


**Figure 2. Relation between yarn size and weight**

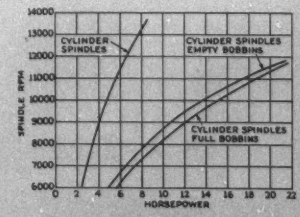


**Figure 3. Breakdown test on 216-spindle frame, $2^1/_4$-inch-diameter ring**

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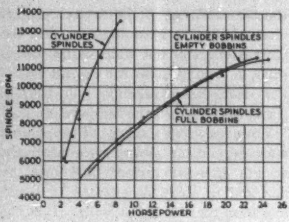


**Figure 4. Breakdown test on 216-spindle frame, $2^1/_2$-inch-diameter ring**

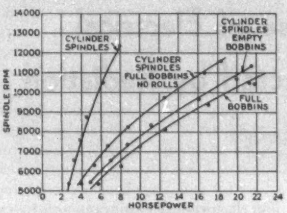


**Figure 5. Breakdown test on 216-spindle frame, $2^3/_4$-inch-diameter ring**

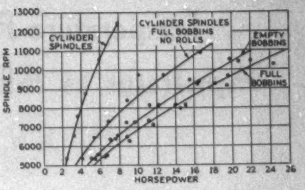


**Figure 6. Breakdown test on 216-spindle frame, 3-inch-diameter ring**

bers spun in cotton mills vary so widely that no attempt has been made here to cover all conditions, but the figures given will serve as a basis for the more common combinations.

Power readings were taken while spinning yarn at the empty-bobbin position, and again at the full-bobbin position for each diameter of ring, over a range of spindle speeds from approximately 6,000 rpm to 11,500 rpm, the upper range being considerably beyond the point of practical spinning, but as in the previous tests, this was necessary to establish the characteristics of the frame.

Figures 3 and 4 show the power requirements when spinning with $2^1/_4$- and $2^1/_2$-inch-diameter rings, with medium-large spindles.

The power curve for the cylinder and bare spindles is also plotted.

Figures 5 and 6 show the power requirements when spinning with the $2^3/_4$- and 3-inch-diameter rings with the large spindles. It is interesting to note on the breakdown tests on these larger ring diameters that the power required to spin yarn at the empty-bobbin position was considerably more than the power required to drive the spindles with full bobbins, and without the front rolls running. This increase in power is accounted for in the windage and friction of the balloon of the yarn and the traveler.

From the results of both investigations it shows that the cotton-spinning frame

**Table I. Spinning-Frame Tests—Frame Data**

| | |
|---|---|
| Type and model | F2, long draft |
| Number of spindles | 216 |
| Type spindle | large medium 2K, large 4K |
| Whorl diameter | $1^1/_8$ inches |
| Gauge spindle | $4^1/_8$ inches, four boss rolls |
| Width tape | $^3/_8$ inch |
| Traverse | 8 inches |
| Cylinder diameter | 10 inches |
| Cylinder bearings | all ball bearing six-section cylinder |
| Ring diameter | $2^1/_4$, $2^1/_2$, $2^3/_4$, and 3 inches |
| Type of ring | number 2 flange |
| Traveler weight and number | number 10 square point, Bowen |
| Number yarn spun | 10s |
| Yarn spun | warp-filling wind |
| Ply roving | two ply—1.0 hank. Draft 20. Twist per inch 16.10 |
| Type builder | four-point filling |
| Thread board | traversing |
| Diameter front roll | 1 inch |
| Diameter middle roll | $^3/_8$ inch |
| Diameter back roll | $^3/_8$ inch |
| Tape idler pulleys | regular; weight used, $2^1/_2$ pounds |
| Separators | solid aluminum |
| Weight on front rolls | $4^1/_2$ pounds |
| **Gearing:** | |
| Cylinder | 26 teeth |
| Jack | 112 teeth |
| Twist | 88 teeth |
| Front roll | 100 teeth |
| Lay | 53 teeth |
| Crown | 140 teeth |

**Table II. Spindles Per Horsepower for Different Size Yarns at Various Speeds**

| Ring Diameter (Inches) | Spindle RPM | Yarn Size 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| $1^1/_4$ | 12,000 | | | | | | | 27.4 | 28.0 | 28.0 |
| | 11,000 | | | | | | | 32.9 | 33.6 | 33.6 |
| | 10,000 | | | | | | | 39.7 | 40.6 | 40.6 |
| | 9,000 | | | | | | | 49.5 | 50.7 | 50.7 |
| | 8,000 | | | | | | | 63.0 | 64.5 | 64.5 |
| | 7,000 | | | | | | | 82.7 | 84.5 | 84.5 |
| $1^1/_2$ | 12,000 | | | | 19.4 | 20.0 | 20.6 | 21.1 | 21.6 | |
| | 11,000 | | | | 23.35 | 24.1 | 24.8 | 25.4 | 26.0 | |
| | 10,000 | | | | 28.15 | 29.1 | 29.9 | 30.7 | 31.6 | |
| | 9,000 | | | | 35.3 | 36.5 | 37.4 | 38.4 | 39.2 | |
| | 8,000 | | | | 44.7 | 46.2 | 47.5 | 48.7 | 49.8 | |
| | 7,000 | | | | 58.5 | 60.5 | 62.2 | 63.7 | 65.2 | |
| $1^3/_4$ | 12,000 | | | 15.70 | 16.30 | 16.85 | 17.3 | 17.72 | 18.15 | |
| | 11,000 | | | 18.90 | 19.60 | 20.3 | 20.8 | 21.35 | 21.9 | |
| | 10,000 | | | 22.9 | 23.80 | 24.6 | 25.2 | 25.9 | 26.5 | |
| | 9,000 | | | 27.2 | 28.25 | 29.2 | 30.0 | 30.8 | 31.5 | |
| | 8,000 | | | 35.2 | 37.60 | 38.9 | 40.0 | 41.0 | 42.0 | |
| | 7,000 | | | 47.3 | 49.10 | 50.7 | 52.1 | 53.5 | 54.7 | |
| 2 | 12,000 | | 11.44 | 12.4 | 12.87 | 13.3 | 13.68 | 14.0 | 14.35 | |
| | 11,000 | | 13.78 | 14.9 | 15.5 | 16.0 | 16.42 | 16.85 | 17.27 | |
| | 10,000 | | 17.20 | 18.0 | 18.7 | 19.35 | 19.9 | 20.4 | 20.9 | |
| | 9,000 | | 21.46 | 22.5 | 23.3 | 24.1 | 24.8 | 25.4 | 26.05 | |
| | 8,000 | | 27.20 | 28.5 | 29.6 | 30.6 | 31.4 | 32.2 | 33.0 | |
| | 7,000 | | 35.7 | 37.3 | 38.8 | 40.0 | 41.2 | 42.25 | 43.25 | |
| $2^1/_4$ | 11,000 | 11.35 | 12.05 | 12.63 | 13.1 | 13.55 | 13.93 | 14.3 | 14.62 | |
| | 10,000 | 13.70 | 14.58 | 15.25 | 15.85 | 16.4 | 16.85 | 17.25 | 17.7 | |
| | 9,000 | 17.10 | 18.20 | 19.1 | 19.8 | 20.5 | 21.05 | 21.6 | 22.1 | |
| | 8,000 | 21.70 | 23.10 | 24.2 | 25.1 | 26.0 | 26.7 | 27.4 | 28.0 | |
| | 7,000 | 28.40 | 30.20 | 31.7 | 32.9 | 34.0 | 35.0 | 35.8 | 36.7 | |
| | 6,000 | 38.90 | 41.40 | 43.3 | 45.0 | 46.5 | 47.8 | 49.0 | 50.2 | |
| | 5,000 | 56.4 | 60.0 | 62.8 | 65.2 | 67.5 | 69.4 | 71.0 | 72.7 | |

| Ring Diameter (Inches) | Spindle RPM | Yarn Size 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| $2^1/_2$ | 10,000 | | 10.81 | 11.78 | 12.53 | 13.13 | 13.64 | 14.10 | 14.50 |
| | 9,000 | | 13.50 | 14.75 | 15.65 | 16.40 | 17.04 | 17.60 | 18.05 |
| | 8,000 | | 17.10 | 18.70 | 19.82 | 20.80 | 21.75 | 22.30 | 22.9 |
| | 7,000 | | 22.40 | 24.4 | 26.0 | 27.20 | 28.25 | 29.20 | 30.00 |
| | 6,000 | | 30.80 | 33.50 | 35.70 | 37.40 | 38.80 | 40.10 | 41.20 |
| | 5,000 | | 44.50 | 48.6 | 51.60 | 54.2 | 56.20 | 58.00 | 59.5 |
| $2^3/_4$ | 10,000 | 8.17 | 9.45 | 10.3 | 10.95 | 11.47 | 11.9 | 12.30 | |
| | 9,000 | 10.17 | 11.76 | 12.82 | 13.65 | 14.3 | 14.85 | 15.34 | |
| | 8,000 | 12.92 | 14.95 | 16.28 | 17.3 | 18.16 | 18.8 | 19.42 | |
| | 7,000 | 16.95 | 19.6 | 21.3 | 22.7 | 23.8 | 24.7 | 25.50 | |
| | 6,000 | 24.1 | 27.9 | 30.4 | 32.3 | 33.9 | 35.1 | 36.25 | |
| | 5,000 | 33.7 | 38.9 | 42.3 | 45.1 | 47.2 | 49.0 | 50.60 | |
| 3 | 10,000 | 7.24 | 8.36 | 9.1 | 9.68 | 10.15 | 10.54 | | |
| | 9,000 | 9.01 | 10.4 | 11.35 | 12.08 | 12.65 | 13.14 | | |
| | 8,000 | 11.45 | 13.25 | 14.43 | 15.35 | 16.1 | 16.7 | | |
| | 7,000 | 15.05 | 17.4 | 18.9 | 20.15 | 21.1 | 21.9 | | |
| | 6,000 | 20.6 | 23.8 | 25.9 | 27.6 | 28.9 | 30.0 | | |
| | 5,000 | 29.9 | 34.5 | 37.6 | 40.0 | 41.9 | 43.4 | | |

# Temperature Rise of Electrical Apparatus as Affected by Radiation

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ASSOCIATE AIEE

**Synopsis:** Radiation is generally of importance only in apparatus cooled by natural convection and radiation. If such apparatus with a smooth exterior surface is mounted in the sun and shielded from the wind, an additional rise as high as 20 degrees centigrade may occur. White or gray nonmetallic paints may decrease solar effects. Fins and corrugations increase the ratio of convected to radiated heat and thereby decrease radiant effects.

IN electrical engineering, radiation is relatively unimportant in the normal application of most apparatus, but in occasional applications it should be considered.

The subject of radiation has received considerable attention from heating and ventilating engineers.[1,2] It is always considered in computing the amount of refrigeration required for air conditioning. In this case, large areas are exposed to sunlight and small temperature differences are important. In the dissipation of heat from the human body, radiation is normally more important than convection and differences of a few degrees in wall temperature are important.[3]

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The author takes this opportunity to acknowledge the help of G. W. Hewitt, who has conducted some of the tests reported, and contributed many valuable suggestions in the preparation of the manuscript.

1. For all numbered references, see list at end of paper.

In electrical engineering, motors, transformers, and similar apparatus operate at higher temperatures, so that a difference of a few degrees is not as important as in air conditioning. The effect of radiation on the temperature rise depends on the enveloping area of a device. In most devices the cooling obtained from a smooth surface is inadequate, so that finned or corrugated surfaces, forced air circulation, or water cooling are provided. Under these conditions the normal losses of the device per unit of enveloping area are large, so that the radiant effect of hot walls or the sun is small as compared to the normal losses. For such cases radiation will have a negligible effect on the temperature rise.

However, some types of apparatus must depend for cooling on a relatively smooth external surface, and may be mounted in locations exposed to radiation from the sun or hot walls. It is the purpose of this paper to point out the relative magnitudes of these factors and to give curves which will be helpful in estimating the temperature rise under unusual circumstances where radiation is important.

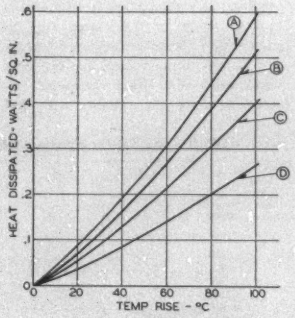



**Figure 1. Heat dissipation–temperature rise curves**

*A*—Radiation from black surface to black surrounding surfaces at 25 degrees centigrade

*B*—Natural convection from a large (two feet or over) surface facing upward

*C*—Natural convection from a large vertical surface

*D*—Natural convection from a large surface facing downward

## Radiation of Heat

The basic law of heat radiation is that any object is radiating heat proportional to the fourth power of the absolute temperature, but all surrounding objects are likewise radiating. If the surfaces are partially reflecting, multiple reflections lead to complicated calculations.

In the case of a sphere or plane surface small as compared to the enclosing space, the heat loss from the small surface becomes independent of the emissivity of the enclosing surface because of multiple reflections within the enclosing

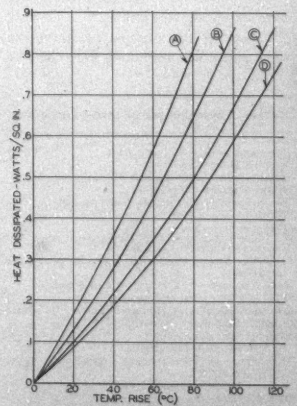



**Figure 2. Heat radiated from a black surface**

*A*—100-degrees-centigrade surrounding surface temperature

*B*—70-degrees-centigrade surrounding surface temperature

*C*—40-degrees-centigrade surrounding surface temperature

*D*—25-degrees-centigrade surrounding surface temperature

has a very definite speed-power characteristic which is not only affected by the number of spindles, but also by the ring diameter and the size of yarn spun. When these conditions are known, it is possible to predict, within reasonably close limits, the power required to drive a spinning frame.

There is a possibility that these machines, like most others, may vary slightly in power requirements even when so-called duplicates are involved. These variations should not affect the horsepower rating of the motors selected to drive the frames, and these data should be of considerable help to the machine manufacturer and the textile manufacturer in selecting the proper-size motor for applying to spinning frames within the scope of these investigations.

space. The heat loss from the small surface is that given by the familiar Stefan-Boltzman law.[15,4]

$$W = 36.9\epsilon_1\left[\left(\frac{\theta_1}{1{,}000}\right)^4 - \left(\frac{\theta_2}{1{,}000}\right)^4\right]$$

$W$* = energy radiated, watts per square inch
$\theta_1$ = temperature of radiating surface (degrees Kelvin)
$\theta_2$ = temperature of the enclosing surface (degrees Kelvin)
$\epsilon_1$ = emissivity of the small surface

The emissivity of any surface is equal to its absorption coefficient. Also, $1-\epsilon=$ reflectivity.

If the radiating object becomes of appreciable size as compared to the enclosing surface, the emissivity of the enclosing surface becomes of importance since, in a reflecting enclosure, radiation from the sphere will be reflected back onto the emitting surface. A. D. Moore[4] has evaluated the heat loss for several typical cases of this type and also the increase in radiation due to grooves or corrugations in reflecting surfaces. Another complication is that in general the emissivity of a surface varies with the wave length of the radiation. For example, white paint reflects a large percentage of solar radiation but is a good absorber for low-temperature radiation. In the case of irregular partially reflecting surfaces, exact calculations are usually too complicated for engineering purposes.[6] Fortunately, most electrical apparatus is painted with a nonmetallic paint which has an emissivity of the order of 0.9 for long wave lengths. The effective surface for radiation is then approximately the same as the enveloping surface. Radiation is in general not of importance in apparatus which is cooled by fans or is water cooled. In dealing with apparatus cooled by natural convection and radiation which must be located adjacent to hot surfaces, it usually is sufficient to compare the relative magnitudes of radiation and convection on the test floor with those calculated for service conditions and from these estimate the temperature under the service conditions. Natural convection varies widely, depending on the shape of the surface and surrounding objects. However, curves are available which give the convection under average conditions, and for many engineering purposes these values will prove sufficiently accurate. Figure 1 compares radiation for 25-degree enclosing walls and convection for large plane surfaces as given by McAdam's equations.[6] Figure 2 gives radiation for several other enclosing surface temperatures. The curves are useful in approximating the temperature rise under conditions near hot walls.

## Solar Radiation

The radiant energy received from the sun has been the subject of many careful measurements.[8,9,10] It fluctuates about seven per cent due to variation in the distance of the sun and sun spots. The radiant energy from the sun as it would be measured by an observer at the earth's mean solar distance but outside our atmosphere, is called the "solar constant."

The mean of 692 determinations of the solar constant in the period from 1902 to 1912 gave a value of 1.94 gram-calories per (minute × centimeter square) or 0.87 watt per square inch.[11]

The intensity of radiation as measured at the earth's surface varies over a wide range, depending on the altitude, humidity, and cloudiness. The curves of figure 3 are plotted from values given in the Smithsonian Physical Tables[11] and give the intensity as a function of wave length for various altitudes and angles of the sun from the zenith. These curves apply to conditions of low humidity and no volcanic dust, so that they give practically maximum values of direct solar radiation.

A large portion of the reduction in solar energy in passing through the atmosphere is due to scattering. Much of this scattered energy reaches the earth as "sky light." This has not been studied as extensively as the direct solar radiation. In general, the scattered radiation or sky light is increased as the direct solar radiation is decreased by a longer path through the atmosphere or by increased haziness. Abbot[12] gives a value of sky light on Flint Island (sea level) of 32 per cent of the direct radiation and for Mount Wilson 7 per cent of the direct radiation.

Taking 0.6 as a typical value of direct radiation at sea level, 32 per cent of 0.6 gives 0.19 watt per square inch as sky light. For Mount Wilson 7 per cent of 0.74 gives 0.05 watt per square inch as sky light. The total radiation received by a horizontal surface with the sun at zenith would then be 0.6+0.19=0.79 for Flint Island and 0.74+0.05=0.79 for Mount Wilson. These meager data would seem to indicate that under favorable conditions a surface at sea level may receive nearly as much total energy as at high altitude, and that this value may be as high as 0.8 watt per square inch. Houghten, Blackshaw, Pugh, and McDermott[1] give values of solar radiation

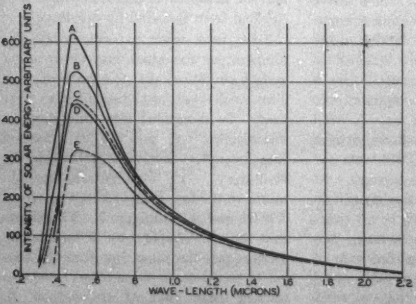



Figure 3. Intensity–wave length curves for direct solar radiation

A—Outside the earth's atmosphere
B—Mount Wilson—5,680-foot elevation, zero degree angle of sun from zenith
C—Mount Wilson—5,680-foot elevation, 60-degree angle of sun from zenith
D—Washington, D. C., 112-foot elevation, zero degree angle of sun from zenith
E—Washington, D. C., 112-foot elevation, 60-degree angle of sun from zenith

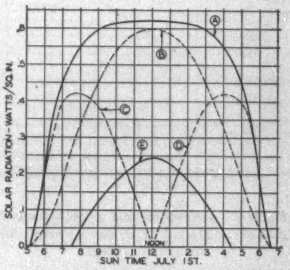



Figure 4. Solar radiation July 1 at Pittsburgh, Pa.

A—Surface normal to sun
B—Horizontal surface
C—East wall
D—West wall
E—South wall

* Watts, inches, and degrees centigrade are generally used in this paper because they are believed to be the most convenient units for the electrical engineer. To convert watts per square inch to Btu per (hour × square feet) multiply by 493; to convert to gram calories per (second × square centimeters) multiply by 0.037.

as measured at the United States Weather Bureau station in Pittsburgh, Pa. Figure 4 gives their values. Their maximum value of radiation is 0.63 watt per square inch. From the data available, the writer considers 0.75 watt per square inch as the typical maximum value of solar radiation (that is, 20 per cent greater than that given by figure 4).

## Effect of Solar Radiation on the Temperature of Apparatus

As has been mentioned, most devices having forced air circulation or water cooling, will have a high loss per unit

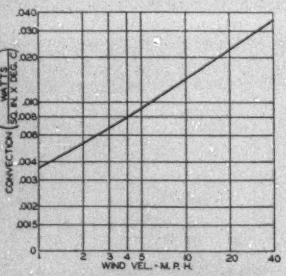



**Figure 5. Convection from six-inch-diameter cylinder as affected by air flow perpendicular to axis of cylinder**

of external projected area exposed to the sun. The heat received from the sun is, therefore, small as compared to the normal losses and has a negligible effect on the temperature rise. Such cases will not be considered further.

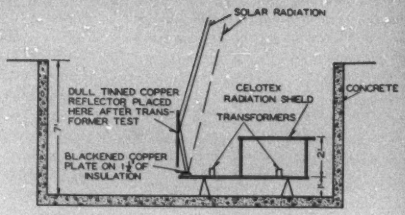
The heat received by apparatus exposed to the sun can be estimated from data on solar radiation. If all parts of the device can be assumed to be at the same temperature, and if the watts lost and temperature rise under test conditions are known, the watts dissipated per degree rise can be calculated. The additional rise due to radiation from the sun can be estimated.

However, under service conditions, several factors tend to reduce the temperature below that which would be obtained in this way.

1. Large apparatus cooled by natural convection and radiation approaches its final temperature slowly so that the solar radiation will be decreasing before the apparatus reaches its maximum temperature.

2. Most locations exposed to the sun will likewise be exposed to wind which will give a greater loss per degree by convection than that obtained in the test floor.

**Figure 6. Diagram of apparatus for measuring temperature rise due to solar radiation**




3. The sky is very seldom cloudless, so that the maximum value of solar radiation is seldom obtained continuously.

Apparatus exposed to the sun receives direct and scattered radiation and radiates to the sky. To be strictly accurate in estimating the radiation from apparatus out of doors, the effective temperature of the sky should be used. However, calculations indicate that for apparatus with a surface rise of 50 degrees centigrade or less, such refinements are not justified by the accuracy of our knowledge of scattered radiation and effective temperature of the sky. The term "sky light" has been applied to the net radiant energy received by a black surface exposed to the sky, taking as zero the condition when the black surface is covered by a radiation shield at ambient temperature. Sky light is, therefore, the difference between the scattered solar radiation falling on the measuring surface and the additional heat radiated from this surface due to the fact that it is exposed to the sky rather than to a surface at ambient temperature. Therefore, in this paper the additional temperature rise of apparatus due to solar radiation will be calculated on the assumption that the apparatus receives both direct solar radiation and sky light, and that the apparatus dissipates its heat as though it were radiating to surfaces at ambient temperature.

Figure 5 is a curve of convection as affected by wind velocity. This curve was plotted from a dimensionless curve given by McAdams.[7] From this curve it is evident that a wind velocity of one mile per hour is sufficient to give a noticeable increase as compared to natural convection in still air. A wind velocity of ten miles per hour gives a convection coefficient of 0.014 watt per (square inch × centigrade degrees). At 40-degrees centigrade rise this gives 0.56 watt per square inch, which is 4.3 times the loss by natural convection. Appendix I considers a simplified case of apparatus exposed to sun and wind simultaneously, showing that a wind velocity of four miles per hour is sufficient to compensate for the heat received from the noonday sun.

Another method of reducing the temperature rise due to solar radiation is to use a paint which reflects much of the short-wave-length radiation, but acts as a good radiator for long wave lengths. White paint may absorb only 25 per cent of solar radiation but 95 per cent of long wave lengths. There would be few locations where a clean white surface could be maintained, but a gray paint showing an appreciable gain might be practical. Metallic pigments as in aluminum paint give a high reflectivity for all wave lengths. This reduces the solar radiation absorbed, but also reduces the dissipation of heat by radiation so that the device will usually operate at a higher temperature than if painted black. Montsinger[13] has discussed this question, and has given several typical curves showing the temperature rise of transformers under service conditions. The wind velocity was not reported, so that his values cannot be used to predict the temperature which would occur under other wind conditions.

## Test Results

Under many conditions there will be sufficient wind so that the increased convection will compensate for the heat received from the sun. Occasionally there are periods of calm, or apparatus may be mounted in locations where it is shielded from the wind by buildings.

Tests were made to demonstrate the temperature rise which may occur under certain conditions due to solar radiation. Two small (100-watt) transformers were used. To determine any differences in manufacture or position of inserted thermocouples, tests were first run in the laboratory. The temperature rise obtained in the first test is plotted in curves *A*1, *B*1, and *AB*2 of figure 7. This shows that the iron temperature of both transformers was the same, but that the copper of transformer *A* ran about 2 degrees warmer than that of transformer *B*. To be certain that both were loaded

equally, the primaries were operated in parallel and the secondaries in series supplying a common lamp load.

To obtain results not influenced by clouds, the field tests were made in Colorado at 38 degrees latitude and at an elevation of 4,200 feet. The first test was made with the transformers supported about one foot above the ground and in a location shielded from the wind by a small building. Transformer *B* was exposed to the sun, while transformer *A* was shaded by a piece of Celotex four feet by four feet supported about two feet above the transformer. The arrangement was similar to that shown in figure 6, except that the test was made on level ground instead of in a pit. The results of this test are shown as curves *A*3 and *B*3 of figure 7. While an attempt had been made to locate the test where it would be shielded from the wind, this was not entirely successful. Especially toward the end of the test, gusts of wind would occasionally give anemometer readings of 75 feet per minute near the transformers. It is believed that the drop in temperature near the end of the test was caused by these gusts of wind. Under these conditions the copper of transformer *B* which was exposed to the sun operated at 17 degrees centigrade greater rise than that of transformer *A* which was shaded, although in the laboratory the copper of transformer *A* had been 2 degrees warmer. The difference due to solar radiation was, then, 19 degrees centigrade.

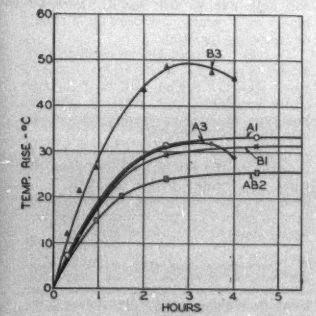



**Figure 7. Time–temperature rise curves of small transformers**

*A*1—Copper temperature of transformer *A* as tested in laboratory

*B*1—Copper temperature of transformer *B* as tested in laboratory

*AB*2—Iron temperature of transformers *A* and *B* as tested in laboratory

*B*3—Copper temperature of transformer *B* exposed to the sun

*A*3—Copper temperature of transformer *A* shaded

To eliminate the effect of the wind, another test was made in a pit 7 feet deep by 15 feet wide with concrete walls. This test arrangement is shown in figure 6. This time transformer *A* was exposed to the sun and transformer *B* was shaded. As would be expected in a location so well shielded from the wind, the ambient temperature rose considerably. For this reason actual temperatures are plotted rather than temperature rise in figure 8. In this test at the end of $2^1/_2$ hours the copper of transformer *A* was 22 degrees warmer than that of transformer *B*. Correcting for the 2-degree difference in the laboratory test, the rise due to radiation would be 20 degrees centigrade. The effect of solar radiation on iron temperatures was to give an additional rise of $20^1/_2$ degrees centigrade. An approximate calculation of temperature for this case is given in the appendix.

To illustrate one unusual condition, a piece of blackened sheet copper was mounted on $1^1/_2$ inches of thermal insulation (wood-pulp packing material). In this way the loss from the back of the sheet metal was small and the area for dissipating heat by convection was the same as the area exposed to radiation. With an ambient of 40 degrees centigrade the sheet metal attained a temperature of 90 degrees centigrade. To illustrate the effect of possible reflections, a piece of dull tinned copper was set up as a reflector as shown in figure 6. This increased the temperature of the blackened metal to 109 degrees centigrade. Or course, many other special tests could be made showing still higher local temperatures. Apparatus under a glass cover gets very hot because most glasses transmit solar radiation efficiently, but are opaque to long wave lengths, so that apparatus under glass receives solar radiation but cannot be cooled by radiation through the glass. Almost everyone is familiar with the use of a lens or parabolic mirror to produce fire, which is an extreme example of high temperature resulting from solar radiation.

## Summary


In apparatus with a smooth exterior surface and without fans or liquid cooling, radiation to surrounding objects is usually more important than convection. In this case, the surface temperature of surrounding objects may be more important than the air temperature.

Solar radiation on clear days may be as high as 0.8 watt per square inch of surface normal to the sun.

The effect of solar radiation on the temperature rise of apparatus with forced air circulation or water cooling is generally negligible.

If apparatus cooled only by natural convection and radiation from a smooth surface is exposed to the sun but shielded from the wind, additional temperature rise may be of the order of 20 degrees centigrade. However, a wind velocity of a few miles per hour can compensate for the solar radiation. The effect of solar radiation can be decreased by white or gray paint.

High local temperatures can result from unusual conditions, a common example being an object with a glass cover. An extreme example is the high temperature at the focus of a parabolic mirror or lens.


## Appendix

Approximate calculations are given for two smooth-exterior, self-cooled devices showing the additional temperature rise resulting from exposure to the sun in still air, and the effect of a slight wind on the temperature rise.

### A. Calculations for 100-Watt Transformers Used in Tests

Under laboratory conditions the transformer case operated at an average temperature rise of 21 degrees centigrade. The total surface area was 81 square inches. Using the curves of figure 1 in approximating the heat dissipated from the case gives, in watts per square inch,

| | |
|---|---|
| Convection loss | 0.055 |
| Radiation ($\epsilon$=0.95), 0.092×0.95= | 0.087 |
| Loss by radiation and convection | 0.142 |

0.142×81=11.5 watts total heat dissipated, which compares with measured losses of 12 watts

When operating in the sun, the total solar radiation from the curves of figure 4 give 13.8 watts at 9 a.m. This value is obtained by multiplying the projected horizontal area by the value per square inch for a horizontal surface from curve *B* of figure 4; the east area by the value given by curve *C*, etc. At 10 a.m., the radiation was 14.2 watts; at 11:00, 13.3 watts, and at noon, 11.6 watts. Averaging these values gives 13.3 watts as the average heat from the sun, which would be received by a perfect black body. The value of emissivity was assumed to be 0.95. The curves of figure 4 were obtained from the weather-bureau station in Pittsburgh, Pa. From the data available, the values for Colorado are probably 20 per cent higher.

Correcting the above average in this way gives

13.3×0.95×1.2=15 watts

as the estimated average solar radiation.

Adding this to the 12 watts electrical losses gives 27 watts, or 0.33 watt per square inch. By trial and error, using figures 1 and 2, we find that 40-degrees centigrade rise gives, in watts per square inch,

| | |
|---|---|
| Radiation (40-degree surroundings) | $0.23 \times 0.95 = 0.205$ |
| Convection loss | 0.126 |
| Total | 0.331 |

This gives an additional surface rise of $40 - 21 = 19$ degrees centigrade. The drop from copper and iron to the surface is not changed, so that all temperature rises should be 19 degrees higher than in the shade, which compares with $20^1/_2$ degrees centigrade in the test values given by figures 7 and 8.

### B. Effect of Wind

To illustrate the effect of the wind, assume that some device (for example, a transformer) in a cylindrical case six inches diameter by ten inches high is mounted on a pole. Assume the case is smooth and at a uniform temperature. Calculating the solar heat input by considering as before the horizontal, east, south, and west projected areas and the corresponding values of radiation, gives an average heat input from 9 a.m. to 12 noon of 39.5 watts or

$\frac{39.5}{244} = 0.162$ watt per square inch of total surface

Assuming that the normal surface rise is 30 degrees centigrade above an ambient of 25 degrees centigrade gives a heat dissipation of

| | |
|---|---|
| Convection loss | 0.085 watt per sq. in. |
| Radiation $0.135 \times 0.95 =$ | 0.128 watt per sq. in. |
| | 0.213 watt per sq. in. |

$0.213 \times 244$ square inches $= 52$ watts normal dissipation

$0.213 + 0.162$ sun effect $= 0.375$ watt per square inch

to be dissipated when exposed to the sun. By trial and error from figure 1

47 degrees centigrade rise gives

| | |
|---|---|
| Convection loss | 0.155 watt per sq. in. |
| Radiation $0.23 \times 0.95$ | 0.22 |
| | 0.375 watt per sq. in. |

We would then expect this device to operate at 17 degrees centigrade additional rise if exposed to the sun with no wind.

A wind of four miles per hour gives from figure 5 a heat dissipation of 0.008 watt per (square inch × centigrade degrees). At 30-degrees centigrade rise, this gives

0.24 watt per square inch convection loss
$0.135 \times 0.95 = 0.13$ watt per square inch radiation

$0.24 + 0.13 = 0.37$ total

In other words, a wind of four miles per hour would increase the convection by an amount equal to the heat received as solar radiation, so that the temperature rise in the sun would be the same as on the test floor.

A wind of ten miles per hour would give a convection coefficient of 0.014 watt per (square inch × centigrade degrees). At 21 degrees centigrade rise this gives

| | |
|---|---|
| Convection loss $(0.014 \times 21) =$ | 0.294 watt per square inch |
| Radiation $0.095 \times 0.95 =$ | 0.09 watt per square inch |
| | 0.384 watt per square inch |

Therefore, a wind of ten miles per hour would dissipate the heat at 21 degrees centigrade rise, or 9 degrees centigrade below normal.

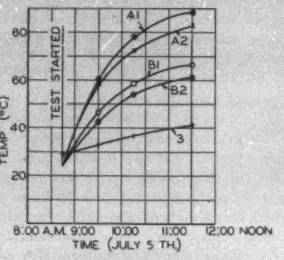



**Figure 8. Time–temperature curves of transformers shielded from the wind**

*A1*—Copper temperature of transformer *A* (exposed to sun)

*B1*—Copper temperature of transformer *B* (shaded)

*A2*—Iron temperature of transformer *A*

*B2*—Iron temperature of transformer *B*

3—Ambient air temperature

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## Discussion

**M. F. Beavers** (General Electric Company, Pittsfield, Mass.): This paper presents some very interesting test data on the effect of solar radiation and wind on the thermal characteristics of small transformers compared to the characteristics under laboratory conditions.

Mr. Penney concludes among other things in his summary that "If apparatus cooled only by natural convection and radiation from a smooth surface is exposed to sun but shielded from the wind, additional temperature rise may be of the order of 20 degrees centigrade. . . ."

This certainly should be a warning to avoid installing small transformers with smooth surfaces in a location shielded from the wind but exposed to the sun for the major part of the day. It is probable that a small percentage of installations fall into this class.

On the other hand, it should not be alarming to those who have made tests or obtained reports to the effect that the temperature rise over ambient of an ordinary oil-immersed pole-type distribution transformer, under actual service conditions, will run only five to ten degrees centigrade higher on a sunny day than on a cloudy day or during the night.

Therefore I would like to recall to your attention some statements in Mr. Penney's paper which, I believe, will tend to show better correlation with previous tests on pole-type distribution transformers under actual service conditions.

Referring to the additional rise due to exposure to the sun but shielded from the wind, Mr. Penney points out that ". . . under service conditions, several factors tend to reduce the temperature below that which would be obtained in this way.

"1. Large apparatus cooled by natural convection and radiation approaches its final temperature slowly so that the solar radiation will be decreasing before the apparatus reaches its maximum temperature.

"2. Most locations exposed to the sun will likewise be exposed to wind which will give a greater loss per degree by convection than that obtained in the test floor.

"3. The sky is very seldom cloudless, so that the maximum value of solar radiation is seldom obtained continuously."

Item number 13 in Mr. Penney's bibliography refers to an article by Montsinger and Wetherill entitled "Effect of Color of Tank on the Temperature of Self-Cooled Transformers Under Service Conditions" in which the results of various tests on distribution transformers located outdoors under normal weather conditions are given.

Table I

| Color of Tank | Oil Temperature Rise—Deg C (1) Min. | (1) Avg.* | (1) Max. | (2) Min. | (2) Avg.* | (2) Max. | (3) Min. | (3) Avg.* | (3) Max. |
|---|---|---|---|---|---|---|---|---|---|
| Black | 4 | 6.9 | 11.5 | 8 | 10.8 | 15 | 20 | 24 | 29.5 |
| Medium gray | 4 | 7.16 | 10 | 10 | 12 | 16.5 | 20 | 23.4 | 29 |
| Light gray | 1.5 | 3.67 | 7.5 | 7 | 10.55 | 14 | 18 | 22.8 | 27 |

(1). Transformer without excitation or load (idle).
(2). Transformer with normal excitation only (no load).
(3). Transformer with normal excitation and normal load.
* Average temperature rise over a 24-hour period.

Figure 1 of the Montsinger-Wetherill paper shows a chart of oil temperature and ambient air temperature for a period of two days for four 5-kva transformers under excitation only (that is, no load). Two of the transformers were in black-painted tanks, one was white, and one was aluminum painted (tests were made in Pittsfield, Mass.).

In order to show the effect of the sun on the transformers in the black-painted tanks I analyzed the oil temperature rise over ambient air for the two-day period from August 12 to 14, 1909. The average minimum oil rise of 7 degrees centigrade occurred in the neighborhood of 4 a.m. to 8 a.m. and the maximum oil rise of 14 degrees centigrade occurred at 6 p.m. The additional rise due to the sun, then, is 14−7=7 degrees centigrade.

With reference to the temperature of the transformers in the white and aluminum-painted tanks Montsinger states ". . . that the transformer with the black tank averages one to two degrees centigrade hotter than the one with the white tank. . . . The temperature of the aluminum-painted tank was as a rule between those of the black and white tanks."

Tests made on several 3-kva lighting transformers in August and September 1922, by Messrs. Moore and Moulton of the San Joaquin Light and Power Corporation are reported in this reference and are summarized in table I of this discussion.

An analysis of the data from which this summary was taken indicates that the maximum oil rise occurs in the vicinity of 6 to 8 p.m. and the minimum oil rise occurs during the early part of the morning with very little increase in rise before 10 a.m.

The additional temperature, then, due to the sun, is the difference between the minimum and maximum oil rises observed. For the Moore-Moulton tests the maximum difference is 9.5 degrees centigrade, on the transformer in the black tank under normal load and excitation.

In regard to the benefits of the gray paint Moore and Moulton concluded that "We have reached the conclusion, after a very careful study of the results herein recorded, that any additional expenditure to procure a gray case instead of black would not be justified."

**V. M. Montsinger** (General Electric Company, Pittsfield, Mass.): I wish to discuss the curves given in figures 1 and 2 of Mr. Penney's paper. In my work I have used curves or equations quite similar to those used by the author. For example: I have used 36.8 for the constant in the radiation formula, and 0.95 for the emissivity factor $e_1$ for all surfaces painted with non-metallic or pigment paints.

The equation of curve $C$ in figure 1 for loss of heat by convection from a large vertical surface appears to be, $W_c = 1.265 \times 10^{-3}\ \theta^{1.25}$, where $W_c$ = watts per square inch and $\theta$ = temperature rise in degrees centigrade. I have used the same form of equation but with a constant of $1.4 \times 10^{-3}$ which gives approximately ten per cent more loss by convection than curve $C$ gives for the same temperature rise.

The curves in figure 1 show that the percentage of losses from a large vertical surface are approximately 60 per cent by radiation and 40 per cent by convection at 25 degrees centigrade. I have found approximately 55 per cent and 45 per cent respectively, the difference being due to the difference in the constants used in the convection formula. This ratio changes with room temperature, since loss of heat by radiation increases with increasing room temperatures, whereas loss by convection is practically unaffected by changes in room temperature. An easy rule to remember is that loss by radiation increases from 1.0 to 1.2 per cent for each degree increase in the room temperature. This is shown by the curves in figure 2. For example: for 60 degrees rise the ratio of the losses in a 100-degree room and a 25-degree room is (0.57/0.30):1.9. That is, the loss is 90 per cent more in a 100-degree room than in a 25-degree room. 90 per cent divided by 75 degrees gives 1.2 per cent increase per degree. For 80 degrees rise the difference between the 40 and 100-degree curves is one per cent per degree. The average value is approximately 1.1 per cent.

For limited temperature rises—up to about 75 degrees—it is possible to approximate closely loss of heat by radiation at various room temperatures by a simple logarithmic equation, as is shown on page 272 of the book on "Transformer Engineering". The equation is:

$$W_r = 1.84 \times 10^{-3} \theta^{1.19} E \left(1 + \frac{1.1\theta_a}{100}\right)$$

where

$W_r$ = watts per square inch
$\theta$ = temperature rise degrees centigrade
$E$ = emissivity factor
$\theta_a$ = room temperature degrees centigrade

Referring again to loss of heat by convection, it should be kept in mind that the constants mentioned before apply only to large vertical surfaces of approximately two feet height and more. For short heights, the constant increases. Some investigators state that the loss varies inversely as the height raised to the one-fourth power. For example: if the loss is unity for a 24-inch height, for a 2.4-inch height the loss would be $(24/2.4)^{1/4} = 1.78$ or 78 per cent more watts per square inch for the same temperature rise. I would like to ask Mr. Penney if he took the height of his 100-watt transformer into consideration when evaluating the ratio of losses by radiation and convection. If not, I am inclined to believe that the effect of the short vertical surface of the 100-watt transformer on the loss by convection was much more than the effect of the low wind velocity.

Referring to my paper—reference 13—as Mr. Penney surmises no record was made of the wind velocity when the field tests were made. The conditions under which the several tests were made correspond to those under which transformers operate in service. As all the tests indicated that the effect of the color of the tank on the relative temperature rise was quite small, two degrees centigrade at the most, it is felt that the conclusions drawn were sound, namely, that the question of the kind of paint used on distribution and power transformers exposed to the sun's rays, is one of appearance and durability only.

**R. E. Hellmund** (Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Mr. Penney's paper gives some very important practical as well as theoretical information on the effects of radiated heat on apparatus. In addition to apparatus intended for outdoor installation, apparatus designed for indoor use is frequently installed outdoors in enclosures of some kind or other. From Mr. Penney's paper it would seem that if these enclosures are ventilated, the sun radiation will have little influence. On the other hand, if the enclosures are not ventilated and if the surface of the enclosure is much larger than the surface of the apparatus enclosed, conditions might be different from those of the transformer discussed in the paper. It would be interesting if Mr. Penney could give in his closing discussion some data regarding installations of this kind.

**R. E. Hellmund** and **F. R. Benedict** (nonmember; both of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Mr. Penney's paper discusses two factors, namely, sun radiation and wind, as affecting temperature conditions of electrical apparatus installed outdoors. It may therefore be appropriate to give some data which have recently become available on outdoor temperatures. In the paper entitled "Temperature Survey of the United States," by J. J. Smith and H. W. Tenney, which was presented at the 1939 AIEE summer convention, some valuable information was given on ambient outdoor temperatures in the United States. It is now generally conceded that the life of insulation is a function of both temperature and time during which certain high temperatures prevail. It is also well known that temperature variations below a certain

safe temperature have little influence upon the deterioration of insulation. In view of this, the electrical engineer is interested principally in ambient-temperature conditions in excess of certain values and the time during which they prevail. The information of this nature given by Smith and Tenney covered seven selected typical stations for the period 1934 to 1938 inclusive, and included curves for the average number of hours per year and the average number of hours per day versus the average number of days per year during which the ambient temperature exceeded 90 degrees Fahrenheit. The paper also gave information for three selected stations for the period 1934 to 1939 inclusive, using 105 degrees Fahrenheit as a basis. These data were prepared from records of the United States Weather Bureau.

It is naturally desirable to have similar data from a larger number of stations, and such data have been made available in tables published in *Heating and Ventilating*, March 1939, under the subject "Number of Hours Per Year of High Dry-Bulb Temperatures." These tables give an analysis of 41 well selected and distributed stations. Three tables are shown, as follows:

**Table 1.** The maximum number of hours in a year that dry-bulb temperature exceeds 85, 90, 95, 100, 105, 110, and 115 degrees Fahrenheit. Maximum in any year from 1932 to 1937 inclusive.

**Table 2.** The average number of hours per year the dry-bulb temperature exceeds 85, 90, 95, 100, 105, 110, and 115 degrees Fahrenheit. Average for the years 1932 to 1937 inclusive.

**Table 3.** The minimum number of hours in a year that dry-bulb temperatures exceed 85, 90, 95, 100, 105, 110, and 115 degrees Fahrenheit for the years 1932 to 1937 inclusive.

From these data the number of hours the ambient temperature exceeds 30, 35, 40, and 45 degrees centigrade can be obtained (85F = 29.4C; 95F = 35C; 105F = 40.5C; 115F = 46.1C).

For our problem the data in table 2 are most pertinent because they cover averages for a period of six years. In a study of the deterioration of insulation we are interested not so much in an individual or maximum-temperature year, but in what happens during the entire life of the equipment. A 6-year period gives a pretty good idea of this, as any variations that may exist between a 6- and a 10- or 20-year period are negligible for the problem at hand.

Referring to table 2, we find that the average number of hours per year during which the temperature exceeds 35 and 45 degrees centigrade for the station having the maximum average number of hours above the given temperature is as follows:

| Deg C | Hours | Station |
|---|---|---|
| 30 | 1,084 | Dallas, Tex. |
| 35 | 292 | Topeka, Kans. |
| 40 | 37 | Topeka, Kans. |
| 45 | 0 | |

Expressed in percentage of total hours per year (8,760 hours), this leads to table *A* in figure 1 of this discussion.

As will be seen, the maximum hours for a given temperature do not all occur at the same station and thus no individual piece of apparatus is exposed to conditions quite as severe as those indicated in the table. It is therefore quite safe to state that, for our problem, the figures in table *A* represent the "maximum climatic ambient temperatures" in the United States. It may well be contended that the use of the maximum ambient conditions met by all electrical apparatus will lead to poor economy in the application of the large majority of apparatus. Reference to table 2, *Heating and Ventilating*, March 1939 indicates that the stations which are of high average are localized in Texas, Oklahoma, Kansas, Arkansas, and Louisiana. If stations in these areas are eliminated, the station with the maximum average number of hours at the given temperatures will then be as follows:

| Deg C | Hours | Station |
|---|---|---|
| 30 | 892 | Kansas City, Mo. |
| 35 | 248 | Kansas City, Mo. |
| 40 | 32 | Kansas City, Mo. |
| 45 | 0 | |

In considering the elimination of some stations or areas, the number of motors and horsepower installed in the various states in which the high-average stations were located, was taken into account. The paper by Smith and Tenney gives sufficient data to show that the elimination of Texas, Oklahoma, Kansas, Arkansas, and Louisiana involves only 3.05 per cent of the total number of motors and 3.9 per cent of the total horsepower installed (probably less than 5 per cent of all electrical apparatus). On the basis of an 8,760-hour year, the predominant climatic ambients for the areas in which over 95 per cent of all electrical apparatus is installed would then be as shown in table *B*, figure 1.

Stated in another way, it would be expected that the ambient temperature would be above 30 degrees centigrade ten per cent of the time or less; above 35 degrees centigrade three per cent of the time or less; above 40 degrees centigrade 0.5 per cent of the time or less; and above 45 degrees centigrade such a small part of the time that for all practical purposes it can be considered as zero.

It may be of interest to consider only the essential industrial areas of the country.

**Figure 1**

Circles indicate weather - bureau stations

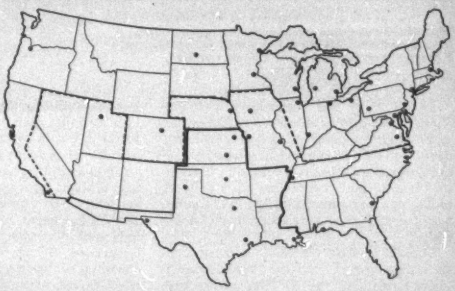

Table *A*. Climatic Ambient for the Country on the Basis of Maximum-Hour Station

| Temperature Below (Deg C) | Per Cent of Time |
|---|---|
| 30 | 88 |
| 35 | 97 |
| 40 | 99.5 |
| 45 | 100 |

Table *B*. Climatic Ambient for the Country After Eliminating Stations Below the Solid Line

| Temperature Below (Deg C) | Per Cent of Time |
|---|---|
| 30 | 90 |
| 35 | 97 |
| 40 | 99.5 |
| 45 | 100 |

Table *C*. Climatic Ambient for the Country After Eliminating Stations Below the Dotted Line

| Temperature Below (Deg C) | Per Cent of Time |
|---|---|
| 30 | 95 |
| 35 | 99 |
| 40 | 99.5 |
| 45 | 100 |

This can be done by excluding North Carolina, Tennessee, and the states south thereof, the southwest corner of Illinois, the states of Iowa and Nebraska and those south thereof, the states Arizona, Nevada, Utah, and New Mexico, and the southeast corner of California. We then find conditions as shown in table *C*, figure 1, for the areas included.

As a matter of course, the values in these tables apply also for any well-ventilated indoor areas where the indoor temperature is about the same as the outdoor. In indoor areas not so well ventilated and in which the electrical and other heat-generating apparatus is small compared with the space available, conditions should be even more favorable. On the other hand, in poorly ventilated indoor areas having a relatively large amount of heat-generating electrical apparatus and other heat-producing devices such as turbines, steam pipes, etc., conditions may be less favorable. Unfortunately, very few reliable data are available for such cases. There may also be indoor installations, especially in factory buildings with glass roofs, where the heat from sun radiation may raise the indoor temperature above the outdoor. Since these last two conditions may apply to an appreciable percentage of electrical apparatus, the compilation of data for installations of this nature seems desirable. However, the ambient temperature conditions given in this discussion, together with the information in Mr. Penney's paper and the Smith and Tenney paper should be of value in the application of electrical ap-

# Phase Occurrence of Arc-Backs in High-Current Mercury-Arc Rectifiers

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THE phenomenon of arc-back in mercury-arc rectifiers is the major factor in determining present-day designs. To keep the frequency of occurrence of arc-back sufficiently low, the anodes are set at a sufficient distance from the cathode, shields, baffles, and grids are interposed, and cooling water temperatures are kept in a rather narrow range. These practically successful means for overcoming arc-backs were developed largely empirically as the cause and nature of arc-back is still little understood.

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The authors wish to thank Doctor Joseph Slepian, who proposed collecting and publishing the data of this paper, and who is responsible for some of the suggestions in interpretation of the results.

1. For all numbered references, see list at end of paper.

In the normal operation of rectifiers, a transient small inverse current flows to each anode just after its voltage polarity reverses at the end of each normal current-conducting period. This inverse current is a maximum just after transition from the normal conducting to normal insulating state of the anode, and decreases rapidly to a small fraction of its initial value in less than ten electrical degrees, under usual operating conditions. The inverse current is believed to consist of positive ions reaching the anode from the rapidly disappearing residual ionization left before the anode in the preceding conduction period. Most investigators express a belief in a strong causal relationship between this inverse current and the arc-back frequency. The fact that the means mentioned in the preceding paragraph for reducing arc-back frequency also reduce greatly the inverse current seems strongly to support this view. Prince and Vogdes,[1] however, state that "if there is any connection between arc-back and the inverse current, it is probably rather remote."

Little is known as to where in the alternating cycle arc-back occurs. If the

**Table I. Arc-Back Data for Rectifiers Tested**

| Rectifier Tested | Load Amperes | Load Volts | Point on Inverse Cycle at Which Arc-Back Occurred* |
|---|---|---|---|
| Six-phase ignitron | 1,250 | 300 | T |
| | 1,250 | 300 | T |
| | 1,250 | 300 | T |
| | 1,250 | 300 | T |
| | 1,250 | 300 | T |
| | 1,250 | 300 | T |
| | 1,875 | 300 | T |
| | 1,875 | 300 | T |
| | 1,875 | 300 | T+26 deg |
| | 1,875 | 300 | T |
| Six-phase multianode rectifier | 2,400 | 600 | T |
| | 3,750 | 600 | T |
| | 3,750 | 600 | T+37 deg |
| Six-phase ignition | 1,250 | 600 | T+170 deg and T+36 deg |
| | 1,250 | 600 | T+68 deg |
| | 1,250 | 600 | T+47 deg |
| | 1,250 | 600 | T+26.6 deg |
| | 1,250 | 600 | T+20 deg |
| Three-phase ignitron | 400 | 600 | T+13 deg |
| Six-phase ignitron | 3,000 | 300 | T+20 deg |
| | 2,500 | 300 | T+27 deg |
| | 2,500 | 300 | T |
| | 2,500 | 300 | T+16 deg |
| | 2,500 | 300 | T+6.5 deg |
| | 2,500 | 300 | T |
| Six-phase ignitron | 1,000 | 600 | T |
| | 1,000 | 600 | T+30 deg |
| Six-phase ignitron | 2,500 | 600 | T |
| | 2,500 | 600 | T |
| | 2,500 | 600 | T |
| | 1,700 | 600 | T |
| | 1,700 | 600 | T+22 deg |
| Six-phase ignitron | 2,500 | 600 | T |
| | 2,500 | 600 | T |
| | 3,750 | 600 | T |
| | 2,500 | 600 | T+23 deg |
| | 2,500 | 600 | T |
| | 2,500 | 600 | T |
| | 6,000 | 600 | T+53 deg |
| | 6,000 | 600 | T+79 deg |
| | 2,500 | 600 | T |
| | 3,750 | 600 | T+80 deg |
| | 3,750 | 600 | T |
| | 7,500 | 600 | T+93.5 deg |
| | 7,500 | 600 | T |
| | 7,500 | 600 | T |
| | 5,000 | 600 | T+128 deg |
| | 5,000 | 600 | T |
| | 7,500 | 600 | T |
| | 7,500 | 600 | T |
| | 5,500 | 600 | T+36 deg |
| | 6,000 | 600 | T |
| | 2,500 | 600 | T |
| | 2,500 | 600 | T |
| Single-phase full-wave ignitron | 400 | 600 | T |
| | 400 | 600 | T+85 deg |
| | 400 | 600 | T |
| | 300 | 600 | T |
| | 600 | 600 | T+76 deg |
| | | 600 | T |
| | 200 | 600 | T+90 deg |
| | 600 | 600 | T+38.5 deg |
| | 600 | 600 | T |
| | 400 | 600 | T |
| | | 600 | T |
| | 800 | 600 | T+106 deg |
| | 800 | 600 | T+56 deg |
| | 800 | 600 | T+82 deg |
| | 200 | 600 | T+36 deg |
| | 200 | 600 | T+23 deg |
| | 200 | 600 | T+77 deg |
| | 800 | 600 | T+93 deg |
| | 800 | 600 | T+54 deg |
| | 800 | 600 | T+127 deg |

*T = Transition.

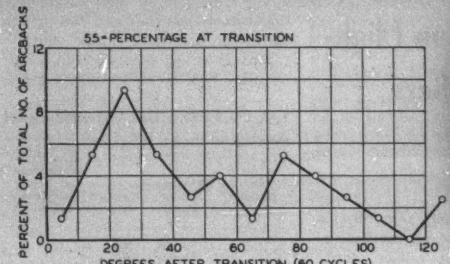
paratus, particularly transformers, the greater number of which are outdoors or in well-ventilated areas.

**G. W. Penney:** Natural convection depends on low-velocity air movements and therefore varies with the shape and size of the surface, type of ventilation in the room, and similar factors which are not normally closely controlled, so that rather large variations are to be expected between results obtained under various conditions. W. H. McAdams in his book on "Heat Transmission"[6] has compiled a good summary of available data. The curves of figure 1 are believed to represent average conditions for large objects.

As Mr. Montsinger mentions, natural convection for small objects is frequently assumed to vary inversely as the one-fourth power of the height, but this simplification usually requires some adjustment of constants. McAdams (page 244) gives a curve showing the variation of convection with height of cylinder which would give convection as varying inversely with a fractional power of the height up to 10 inches and then gradually changing to a constant value for heights over 18 inches. In reply to Mr. Montsinger's question as to the value used for the 100-watt transformer mentioned in the paper, if we use the formula for convection as a function of height as given by McAdams on page 245, equation 32, a value of 12 per cent greater than that given by figure 1 would be obtained. However, the transformer was tested sitting on a wooden platform as shown in figure 6. This platform somewhat obstructed the natural convection so that it was believed that the curves of figure 1 probably came very close to the actual condition.

Heat dissipation due to wind velocity depends on the size of the object and is also commonly approximated as varying inversely as the one-fourth power of the size of the object cooled so that the relative effect of the wind tends to be independent of the size of the object cooled.

Mr. Hellmund asked as to the effect of mounting apparatus in small outdoor enclosures, these enclosures being exposed to the sun. If the enclosure is not ventilated and if its temperature could be assumed to be uniform, the approximate methods suggested in the paper could be used to estimate the effect of the sun. Such a calculation would give an idea of the order of magnitude of the sun effect. However, the temperature throughout the case will not be uniform, and the sources of heat will be irregularly located so that tests should be made if exact figures are needed. A number of tests under typical operating conditions would be desirable.




ARCBACK DISTRIBUTION AFTER TRANSITION FOR MERCURY ARC RECTIFIERS AT CURRENTS OF 100 TO 1200 AMPERES PER ANODE 600 VOLTS MACHINE LOAD

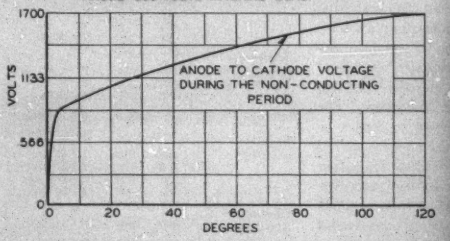



**Figure 1 (above). Arc-back distribution and inverse voltage of a mercury-arc rectifier**

**Figure 2a. Oscillogram of an arc-back which occurred at transition**

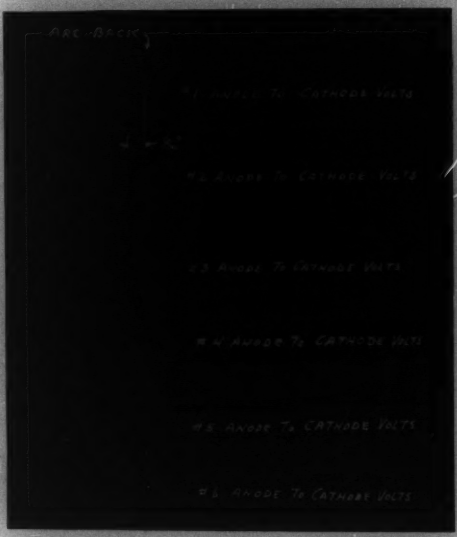



**Figure 2b. Oscillogram of an arc-back which occurred 86 degrees after transition**

inverse current is the controlling cause, then all arc-backs should occur immediately after transition, since under normal operating conditions for low-voltage rectifiers, there is considerable inverse current only just after transition. Actually the belief is quite widespread that arc-backs occur almost entirely at transition. Prince and Vogdes,[2] however, give a contrary viewpoint, and describe experiments with a tube in which quite definitely the arc-backs did not take place at transition. However, the tube used in their experiments was very special, so that it might still be believed that in practical low-voltage rectifiers, arc-backs occur only at transition.

It is difficult to determine the time of occurrence of arc-backs by usual oscillographic means with rectifiers operating under normal conditions, because of their completely random and infrequent occurrences. However, the development of the "memnoscope"[3] has solved these difficulties so that there has now accumulated a considerable number of oscillographic records which permit a direct determination of the time of occurrence of arc-backs in practically operating rectifiers. These records indicate that arc-backs occur frequently throughout the whole inverse period.

**Table II. Per Cent of Arc-Backs at Transition for Each Rectifier Unit**

| Rectifier Tested | Number of Arc-Backs Observed | Per Cent at Transition |
|---|---|---|
| Six-phase ignitron, 300 volts | 10 | 90 |
| Six-phase multianode tank rectifier, 600 volts | 3 | 67 |
| Six-phase ignitron, 600 volts | 5 | 20 |
| Three-phase ignitron, 600 volts | 1 | 0 |
| Six-phase ignitron, 300 volts | 6 | 33 |
| Six-phase ignitron, 600 volts | 2 | 50 |
| Six-phase ignitron, 600 volts | 5 | 80 |
| Six-phase ignitron, 600 volts | 22 | 66 |
| Single-phase full-wave ignitron, 600 volts | 20 | 35 |

## Test Conditions and Procedure

All the oscillograms were taken on the test floor or in the laboratory, on commercial 300- and 600-volt rectifiers feeding a d-c motor. Currents ranged from 100 to 1,250 amperes per anode with zero ignition angle.

Anode to cathode voltages of all the anodes of a rectifier under observation were brought to memnoscopes whose outputs were passed through the elements of a magnetic oscillograph with continuously rotating cylindrical film. On occurrence of an arc-back, a reverse-current relay opened the oscillograph shutter, and a photographic record was thus obtained of the anode to cathode voltages preceding, during and after the arc-back. From these oscillographs the time of occurrence of the arc-back could be determined.

## Results

Seventy-four oscillograms were obtained with arc-back occurrence times, as shown in table I. Two typical oscillograms are shown in figures 2*a* and 2*b*.

Forty arc-backs or 54 per cent occurred at transition. The remaining 34 or 46 per cent were distributed through the inverse period.

# Station-Type Lightning-Arrester Performance Characteristics

AIEE LIGHTNING-ARRESTER SUBCOMMITTEE

THIS PAPER presents the results of additional work by the AIEE lightning arrester subcommittee and contains station-type-arrester performance values which may be expected of present-day commercial station-type arresters rated from 3 to 245 kv. The characteristics of line-type arresters were presented by the subcommittee in the May 1937 and November 1938 issues of ELECTRICAL ENGINEERING.

Table I includes station-arrester impulse gap breakdown values obtained from tests using the rate of voltage rise specified in the AIEE Standards for lightning arresters No. 28 or ASA Standards C-62; that is 100 kv per microsecond per 11.5 kv of arrester rating. To enable a more complete analysis of arrester performance, a complete curve (figure 1) of arrester gap breakdown voltage is included as a supplement to the tabulated values. This curve is plotted in per cent of the arrester's maximum permissible line-to-ground voltage rating, using the crest value of the voltage rating as the 100 per cent of reference point. The actual breakdown voltage for any arrester at any time $T$ can be obtained by multiplying the crest value of the arrester's maximum permissible line to ground voltage rating by the percentage value indicated for any time $T$ on the curve.

The 60-cycle spark potential of the arresters referred to in this report will not be less than 150 per cent of the arrester's maximum permissible line-to-ground voltage rating.

The table of arrester-performance values also includes the $IR$ discharge voltage of the arrester valve element for currents of 1,500, 3,000, 5,000, 10,000, and 20,000 amperes, all of which are based on a current wave having a time to crest value of 10 microseconds and a time to 50 per cent of the crest value on the tail of the wave of 20 microseconds.

The lightning-arrester manufacturers have furnished the data from which the average characteristics of available station arresters are plotted and tabu-

Paper 40-62, prepared by the lightning-arrester subcommittee of the AIEE committee on protective devices, recommended by the AIEE committee on protective devices, and presented at the AIEE winter convention, January 22–26, 1940. Manuscript submitted June 14, 1939; made available for preprinting December 28, 1939; released for final publication February 23, 1940.

Personnel of AIEE lightning-arrester subcommittee: L. R. Ludwig, chairman; H. W. Collins, H. A. Dambly, J. M. Flanigen, I. W. Gross, Herman Halperin, J. C. McFarlin, J. R. North, H. L. Rorden, W. J. Rudge, A. H. Schirmer, H. K. Sels, L. G. Smith, H. R. Stewart, and E. R. Whitehead.

The curve of figure 1 shows the distribution of these 34 arc-backs through the inverse period. Only one was observed at more than 130 degrees after transition. It occurred at 170 degrees and another anode arced back a few degrees later.

By direct experiment with a deck of cards it was found that the curve of figure 1 is not inconsistent with the hypothesis that the probability of arc-back is the same in each of the 10-degree intervals making up the 130 degrees. That is, 34 points placed at random in the 13 10-degree intervals gave distributions with as great a saw-tooth irregularity as shown in figure 1.

## Discussion

The fact that only one arc-back was observed at more than 130 degrees later than transition may have been not because the later ones have a lower probability of occurrence, but rather to the method used for tripping the oscillograph shutter. On the six-phase rectifiers the oscillograph shutter was tripped by the reverse-current breaker, hence no record of arc-backs which clear without fault, if there are such arc-backs, was obtained.

There are not a sufficient number of arc-backs to obtain the true form of the distribution curve. About all that can be said definitely from the results obtained is that not all arc-backs have a probability of occurrence which is a strongly varying function of the instantaneous positive ion current density. The most that can be said in this direction would be that there are several types of arc-backs; and that one type, which constituted 54 per cent of the total, is occasioned by the momentary positive-ion current.

On the other hand, other possibilities will fit the above results. For example, we may postulate that arc-back causes occur at random throughout the cycle, but with effects lasting a cycle or more. In this case all causes which occur during the conducting period will produce their effect at transition and their number will depend on ratio of conducting to nonconducting period in the rectifier. If there is an equal probability for the whole inverse period, then for the double three-phase rectifier connection we should obtain $230°/360°=63.8$ per cent of the arc-backs after transition and 36.2 per cent at transition. However, as can be seen from table II for the nine rectifiers tested, the fraction for each rectifier occurring at transition is very variable, which makes the possibility just discussed rather unlikely.

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2. Reference 1, page 71.

3. A MEMORY ATTACHMENT FOR OSCILLOSCOPES. W. E. Pakala. AIEE TRANSACTIONS, volume 57, 1938, pages 682–4.

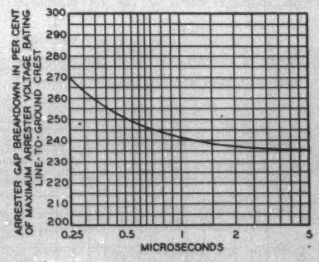


**Figure 1. Impulse gap breakdown, tolerance ±20 per cent**

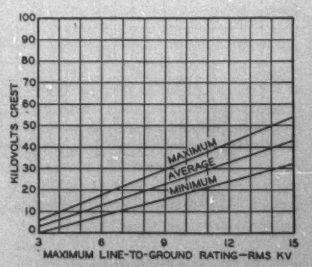


**Figure 2. Impulse gap breakdown based on AIEE wave**

**Table I. Industry Station-Type Arrester Characteristics**

All *IR* Voltages on 10–20-Microsecond Current Wave; Kilovolts Crest

| | Gap Breakdown on AIEE Rate | | | IR at 1,500 Amp. | | | IR at 3,000 Amp. | | | IR at 5,000 Amp. | | | IR at 10,000 Amp. | | | IR at 20,000 Amp. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kv* | Avg. | Min. | Max. | Avg. | Min. | Max. | Avg. | Min. | Max. | Avg. | Min. | Max. | Avg. | Min. | Max. | Avg. | Min. | Max. |
| 3 | 13 | 10 | 16 | 9 | 8 | 10 | 10 | 9 | 11 | 10 | 9 | 11 | 11 | 9 | 13 | 12 | 10 | 14 |
| 6 | 23 | 18 | 28 | 18 | 15 | 21 | 19 | 16 | 22 | 20 | 17 | 23 | 22 | 19 | 25 | 24 | 20 | 28 |
| 9 | 35 | 28 | 42 | 27 | 23 | 31 | 29 | 25 | 33 | 30 | 26 | 34 | 33 | 28 | 38 | 35 | 30 | 40 |
| 12 | 43 | 34 | 52 | 36 | 31 | 41 | 38 | 32 | 44 | 40 | 34 | 46 | 44 | 37 | 51 | 47 | 40 | 54 |
| 15 | 53 | 42 | 64 | 45 | 38 | 52 | 47 | 40 | 54 | 50 | 43 | 57 | 54 | 46 | 62 | 59 | 50 | 68 |
| 20 | 72 | 58 | 86 | 60 | 51 | 69 | 64 | 54 | 74 | 67 | 57 | 77 | 72 | 61 | 83 | 78 | 66 | 90 |
| 25 | 89 | 71 | 107 | 74 | 63 | 85 | 79 | 67 | 91 | 83 | 71 | 95 | 90 | 77 | 103 | 100 | 85 | 115 |
| 30 | 106 | 85 | 127 | 89 | 76 | 102 | 95 | 81 | 109 | 100 | 85 | 115 | 108 | 92 | 124 | 118 | 100 | 136 |
| 37 | 131 | 105 | 157 | 110 | 94 | 126 | 117 | 100 | 134 | 124 | 105 | 143 | 132 | 112 | 152 | 145 | 123 | 167 |
| 40 | 136 | 109 | 163 | 119 | 101 | 137 | 127 | 108 | 146 | 134 | 114 | 154 | 144 | 122 | 166 | 153 | 130 | 176 |
| 50 | 178 | 143 | 213 | 149 | 127 | 171 | 158 | 134 | 182 | 167 | 142 | 192 | 179 | 152 | 206 | 191 | 163 | 219 |
| 60 | 214 | 171 | 257 | 179 | 152 | 206 | 191 | 162 | 220 | 200 | 170 | 230 | 217 | 185 | 249 | 234 | 199 | 269 |
| 73 | 261 | 209 | 313 | 217 | 185 | 249 | 232 | 197 | 267 | 245 | 208 | 282 | 262 | 223 | 301 | 283 | 241 | 325 |
| 97 | 345 | 276 | 414 | 289 | 246 | 332 | 308 | 262 | 354 | 323 | 275 | 371 | 349 | 297 | 401 | 377 | 321 | 433 |
| 121 | 430 | 344 | 516 | 360 | 306 | 414 | 384 | 326 | 442 | 403 | 343 | 463 | 438 | 372 | 504 | 470 | 410 | 530 |
| 145 | 515 | 412 | 618 | 431 | 366 | 496 | 461 | 392 | 530 | 487 | 414 | 560 | 523 | 445 | 601 | 564 | 480 | 648 |
| 169 | 602 | 482 | 722 | 502 | 427 | 577 | 538 | 457 | 619 | 566 | 481 | 651 | 610 | 519 | 701 | 658 | 559 | 757 |
| 195 | 691 | 553 | 829 | 578 | 491 | 665 | 617 | 519 | 715 | 647 | 550 | 744 | 698 | 593 | 803 | 755 | 642 | 868 |
| 242 | 860 | 688 | 1,032 | 720 | 612 | 828 | 768 | 653 | 883 | 806 | 685 | 927 | 872 | 741 | 1,003 | 940 | 799 | 1,081 |

* Maximum permissible line-to-ground voltage rating.

lated. These values hold for new arresters and do not necessarily hold for the older types of arresters.

Tolerances are given to include the expected variation from the average values referred to above. The tolerance from the average value of gap breakdown is ±20 per cent and the tolerance from the average value of the *IR* discharge voltages is ±15 per cent.

By comparing the complete volt-time curve of the arrester with the complete volt-time characteristic of the insulation to be protected, a reasonable evaluation can be made of the margin of protection obtained.

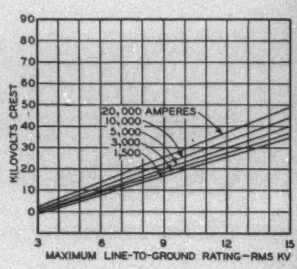


**Figure 4. IR discharge voltage, 10–20-microsecond wave; tolerance ±15 per cent**

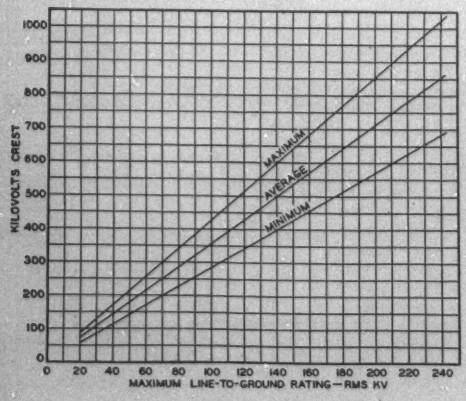


**Figure 3. Impulse gap breakdown based on AIEE wave**

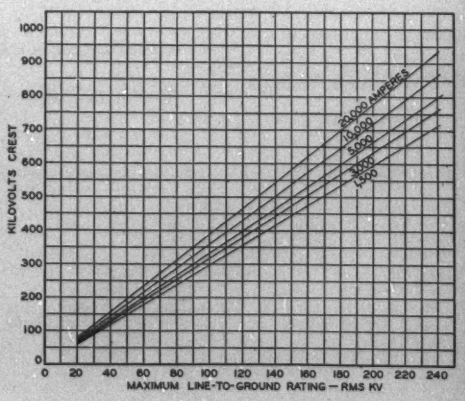


**Figure 5. IR discharge voltage, 10–20-microsecond wave; tolerance ±15 per cent**

# The Measurement of Spot-Welding Current

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CURRENT is an essential factor in the complete specification of spot-welding conditions. Therefore, the need for the measurement of spot-welding currents arises, if optimum conditions determined in experimental laboratories are to be duplicated in production shops. Laboratory methods must be accurate and supplemented by facilities for ready calibration into secondary amperes. Shop methods must be convenient, reasonably accurate, and free from the possibility of accidental error. Shops find current measurement of great value in resetting welding machines for conditions which have previously been found satisfactory.

The problem is complicated by several factors, chief of which is the duration of current flow, which is commonly of the order of one-tenth second, but may be more or less. Another factor is the variable transient current produced by nonsynchronous closure of the welding circuit. A third factor is the wave shape of the welding current. Methods which depend upon the peak value of the current, or the rate of change of the current as it passes through its zero value, will be satisfactory for sinusoidal current waves. However, such methods will be of no value with wave shapes such as are produced by phase control of the firing of mercury-vapor tubes, or the wave shapes of stored-energy discharges.

The present paper includes brief descriptions of a variety of methods of current measurement, together with our evaluation of the methods, based upon experience in using them in spot-welding research programs, and upon the work of Mr. Muller in the preparation of his master's thesis. More recently a number of tests involving simultaneous determination by different methods have been made for the comparisons presented in this paper. The necessary calibrations to convert readings to secondary amperes were also performed. The magnetizing currents for the welding machine were determined through the range of the comparison tests to establish corrections for primary current readings.

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## Methods of Current Measurement

Figure 1 diagrammatically illustrates various methods of measuring spot-welding current. The solid lines connecting the instruments to the welding circuit indicate the connection which we prefer to use. The dotted lines indicate alternate methods of connection. We shall discuss these methods individually in the following order:

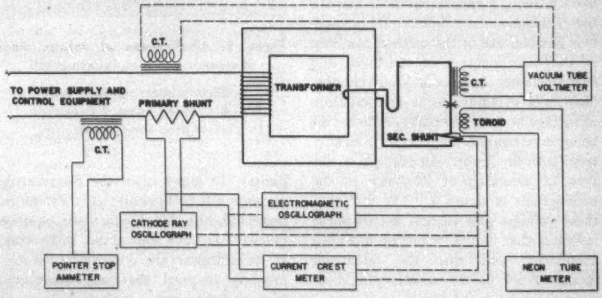


**Figure 1. Various methods of measuring spot-welding currents**

1. Electromagnetic oscillograph with secondary shunt
2. Electromagnetic oscillograph with primary shunt
3. Current-crest meter
4. Cathode-ray oscillograph with primary shunt
5. Pointer-stop ammeter with primary clamp-on current transformer
6. Vacuum-tube voltmeter with secondary current transformer
7. Neon-tube meter with secondary toroid

### Electromagnetic Oscillograph—Secondary Shunt

The shunt used with this method is a hollow cylinder of manganin, built into one of the water-cooled electrode holders. The first shunt built for this purpose was silver soldered into the copper electrode holder but this method was found to have softened the copper to an objectionable degree, so that later a double male-threaded construction was adopted. Potential connections to the shunt are of the knife-edge type usually employed for the precise determination of low resistances in the Kelvin double bridge Figure 2 shows a photograph of the arrangement of connections and location of the secondary shunt in the electrode holder. The resistivity of the manganin was determined with the material in the form of a hollow cylinder, about six inches long, in a Kelvin double bridge. The cylinder had an external diameter of one and one-quarter inches and an internal diameter of one-half inch. Calculation shows that the skin effect of this bar is negligible. A twisted pair of conductors carry the potential connections away from the shunt in a direction perpendicular to the electrodes and parallel to the plane of the secondary loop. Care must be taken to avoid the introduction of vertical loops in the circuit, by properly backtracking and arranging the leads at the point where the conductors leave the shunt. The effectiveness of these precautions to eliminate induced voltages from the potential circuit should be checked experimentally. This may be accomplished by taking an oscillogram during the passage of welding current, with the oscillograph connected to the potential circuit which is short-circuited and insulated from the shunt.

The simplicity, directness, and precision of the calibration involved in the use of a secondary shunt make this method a

Figure 2. Arrangement of connections and location of secondary shunt in electrode holder

standard of comparison for other methods. If current were the only measurement desired, a simpler method than the use of the secondary shunt could be used. Our greatest use of the method has been in the determination of resistance and energy values in spot-welding circuits. This involves simultaneous determination of voltage drops in the parts of the circuit being investigated, and current measurement with the shunt. An example of this type of measurement is shown in the oscillograms of figure 3. The fact that these voltages and current are in phase indicates that inductive pickup has been eliminated, and that the quantities measured are purely resistive in character.

### Electromagnetic Oscillograph—Primary Shunt

This method is simpler than the one previously discussed. A shunt for use in the primary circuit is a standard piece of apparatus, which is therefore easy to purchase. It may even be constructed without much difficulty and is simple to calibrate and install. The use of a primary shunt does not involve as much precaution as does the secondary shunt, to avoid the pickup of induced voltages.

In common with all methods involving measurement of primary current, it is necessary to make measurements of transformer ratio for all winding arrangements which are used. The transformer ratios are obtained by dividing the primary voltage by open-circuit secondary voltages. It is also necessary to correct the total primary current for its magnetizing component before calculating the secondary current. It is common practice to measure the magnetizing current under open-circuit conditions, and in the case of a welding machine, to subtract this from the total primary current arithmetically rather than vectorially. This procedure is not much in error since the power factor of the welding machine is usually so low that the magnetizing and load components of the primary current are nearly in

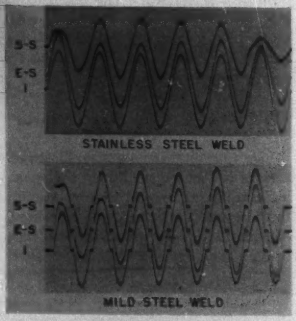


Figure 3. Oscillograms of voltage drops in secondary of spot-welding circuit

*S-S*—Sheet-to-sheet voltage drop
*E-S*—Electrode-to-sheet voltage drop
*I*—Voltage drop across shunt

phase. In many cases the magnetizing currents will be so small that they can be neglected, but this should never be done unless tests have shown this to be true. If transformers are overexcited or improperly designed, the magnetizing currents may be large.

### Current-Crest Meter

This method of measurement uses an electromagnetic-oscillograph element to measure the drop in potential across a shunt in the welding circuit, usually on the primary side of the welding transformer. The oscillograph element deflects a light beam upon a translucent scale, usually graduated in millimeter divisions. No attempt is made to sweep the light beam across the screen and introduce a time axis. The reading of the meter consists in observing the amplitude of the deflection of the spot of light during the passage of the welding current. This reads the peak value of the current. If the wave form of the latter is sinusoidal, the effective value of the current may be calculated by well-known relations. With a little practice an observer may easily read these deflections to a half milli-

meter, and thus determine the welding current with an error of not over two per cent. These readings are most easily taken when synchronous closure of the circuit avoids the introduction of transients. If transients do occur, their magnitude may be observed. Readings may be taken by this method even if the time of current flow is only one or two cycles. The pointer has such low inertia that there is no problem with rapid response such as provides difficulty with an ordinary ammeter or even with the pointer-stop ammeter.

The writers are not acquainted with a meter which is actually manufactured and sold for this purpose. One of the elements of an ordinary portable, two-element

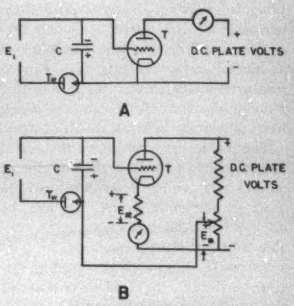


Figure 4. Fundamental vacuum-tube voltmeter circuit

oscillograph has been used by us for this type of measurement. Such a meter would appear to be a very useful laboratory instrument.

### Cathode-Ray Oscillograph—Primary Shunt

A limited amount of experience indicates that a cathode-ray oscillograph may be satisfactorily used in the same way as the current-crest meter above described. The calibration of this meter will not remain permanent so that a means for adjusting the amplifier gain to bring the meter into calibration must be available. A simple circuit, using a voltmeter, variable alternating voltage, and voltage divider, may be set up permanently to accomplish the above calibration easily and as frequently as desired.

A cathode-ray oscillograph is frequently available in a welding laboratory for checking wave forms, transient conditions, and phase-control settings, so that the possibility of using this instrument for current measurement may prove desirable.

A word of caution regarding the use of the cathode-ray oscillograph for current measurement is necessary because of the fact that these instruments are frequently affected by the magnetic field of the welding currents. This difficulty may usually be overcome by placing the instrument at a reasonable distance from the welding machine and by turning the instrument in such a direction as to minimize disturbance. The instrument must be calibrated in the exact position used for current measurement.

### Pointer-Stop Ammeter

This instrument is commercially available together with calibrated leads and a clamp-on current transformer for use on the primary circuit. The ammeter consists of an ordinary instrument to which is added an adjustable stop which may be moved up behind the pointer. In measuring the short-duration spot-welding current, the pointer is gradually

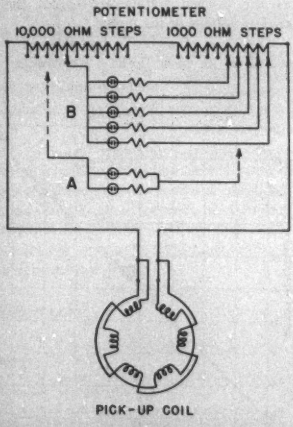


**Figure 5. Fundamental neon-tube meter circuit**

moved up the scale by adjusting the stop until the pointer just leaves the stop when a weld is made. Thus the current does not have to move the pointer all the way up the scale, but only a sufficient distance to indicate that the current is very slightly greater than the value set by the stop. To determine a value of current, it is necessary to make several welds in order to approach the correct setting of the stop for that value of welding current.

This instrument possesses a great advantage in simplicity of reading and ease of attachment to the circuit. It is very suitable for setting a welding machine to a particular value of current. It is necessary only to set the pointer, by means of the adjustable stop, to the value desired and then to adjust the current control until the making of a weld causes the pointer to slightly leave the stop. A further advantage of this method is that it may be used to determine the effective value of phase-controlled currents, which of course are not sinusoidal.

Among the disadvantages of this type of meter are the errors resulting with nonsynchronous circuit closure due to the transients produced, and the optimistic readings resulting from the double-frequency deflecting torque. The deflecting torque periodically varies above and below the control torque. When the pointer is moved up to the value of current which should be indicated, the tendency of the control torque to reduce the deflection below the average value is prevented by the pointer stop. Under these conditions the pulses of the deflecting torque above the average value tend to cause the pointer to jump away from the stop. A false indication of a higher value of current is thus given. In consequence of this we have commonly found a pointer-stop ammeter to consistently read five to eight per cent high. Less significant disadvantages consist of those common to all methods of measuring primary current, and which have already been discussed under the section describing the use of the electromagnetic oscillograph

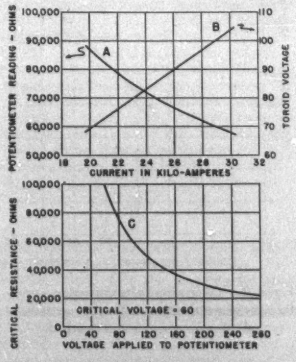


**Figure 6. Characteristics of neon-tube meter circuit**

*A*—Meter calibration
*B*—Toroid characteristic
*C*—Potentiometer characteristic

with a primary shunt. We have found also that the pointer-stop ammeter reading falls off when the time of current flow is three cycles or less. The amount of this falling off is not serious for a welding time of three cycles and amounts to only four per cent in two cycles.

### Vacuum-Tube Voltmeter

Our experience with this type of instrument for the measurement of current has been made possible by the generosity of two men[1,2] who have been responsible for original development work. Each has kindly loaned us his instrument for study. Figure 4 shows the fundamental circuits in which the vacuum-tube voltmeter is used to measure the welding current in terms of the drop in potential across a shunt connected in series with the secondary circuit of a current transformer. The current transformer which we have used is designed for use in the secondary circuit by slipping the transformer over the electrode holder. The basic principle involved in this method is illustrated in figure 4*A*. The voltage drop, $E_1$, across the shunt on the current transformer charges the capacitor $C$ through a rectifying tube $T_R$. This causes the grid of the measuring tube to become more negative, thus reducing the plate current. The capacitor is expected to retain its charge and thus maintain the reduced plate current for a sufficient time to permit reading. Figure 4*B* illustrates a second stage in the development of the circuit of this meter. Two desirable features of adjustability are provided in this circuit. The sliding contact with the indicated voltage drop, $E_B$, permits adjustment of the plate current to the de-

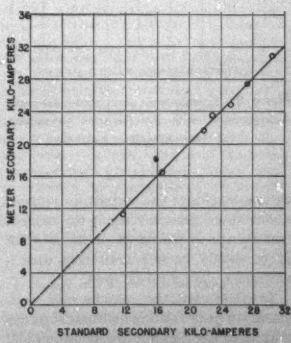


**Figure 7. Comparison of primary-shunt measurements with simultaneous secondary-shunt measurements as a standard using an electromagnetic oscillograph in both cases**

1. For all numbered references, see list at end of paper.

sired top-scale value, before each reading. The resistance associated with the voltage drop $E_R$ in the cathode lead permits adjustment of the over-all sensitivity of the circuit.

One of the principal advantages of this instrument is that the readings are definite and may be obtained with one weld. Also, the secondary current may be measured directly. With circuit refinement to delay the charging of the capacitor the meter may be used to measure welding currents with large transients existing during the first few cycles. Such transients are caused by nonsynchronous closure of the welding circuit, and render inaccurate the measurement of current by almost all methods except the oscillographic.

The difficulties with the vacuum-tube voltmeter are associated with the current transformer and with the fact that it is a peak-reading instrument. The design of an iron-core current transformer to handle such heavy currents involves some sacrifice in portability. The introduction of so much iron into the secondary current loop affects somewhat the output of the welding machine. In our case with a short-throat machine, the output is reduced about three per cent when the current transformer is placed in position. This effect should be less noticeable with a machine of larger throat area.

The fact that the vacuum-tube voltmeter is a peak-reading instrument means that it is not suitable for nonsinusoidal currents such as are caused by the phase control of mercury-vapor tubes. A suggested method of dealing with these currents is impractical to use since it involves the use of full heat, which probably cannot be absorbed by the work.

### Neon-Tube Meter

A meter that employs neon-glow lamps as voltage indicators in conjunction with a potentiometer and pickup coil was also investigated. The circuit of this meter is shown in figure 5. An air-core pick-up coil of the toroidal form is used in the secondary circuit of the welding transformer. The voltage induced in this coil is applied across a potentiometer. The original and basic voltage indicating circuit[3] employs two neon-glow lamps connected in parallel across the same points on the potentiometer as shown at figure 5*A*. Lamps having nearly the same critical voltages are selected for this purpose. As welds are made, the potentiometer connections are progressively changed until a point is reached at which just one of the lamps glows. The magnitude of the secondary current is then obtained directly by reference to the meter calibration.

In the present investigation it was desired to determine the approximate potentiometer setting more quickly and with fewer welds. Therefore a bank of five matched neon-glow lamps is employed as shown at figure 5*B*. By means of switches the entire range of the potentiometer can be explored in four steps. At each step the number of lamps that glow when a weld is made is observed and the approximate setting is that above which all lamps glow. Frequently, however, only one or two welds are necessary to obtain an approximate setting. A high resistance is connected in series with each lamp to avoid the shunting effect of those lamps that pass current. After the approximate setting is determined in this way the final meter reading is determined by means of the basic two-lamp circuit which has already been discussed.

A typical calibration of this meter is shown in figure 6*A*. This calibration was obtained by using the electromagnetic oscillograph and secondary shunt as the standard means of current measurement. The voltage induced in the toroid is a direct measure of the secondary current, if it is sinusoidal. A voltage-current characteristic of the toroid used in this investigation is shown in figure 6*B*. In order to control the voltage applied to the potentiometer, provision is made for connecting the pickup coils in series for measuring low currents and in parallel for high currents. This is very important because, as shown in figure 6*C*, the change in critical resistance for a given change in applied voltage becomes much greater as the applied voltage approaches the critical voltage of the lamps.

This type of meter is probably most useful in its basic form. Its primary advantage is its simplicity and low cost. When used simply as an indicator it does not necessarily have to be calibrated. For example, after the optimum welding conditions have been established for a given job, the reading of the meter can be recorded and then used in checking when the job is set up again at a later date. In our experience this meter was only used in measuring synchronously-timed currents. Its use with nonsynchronous timing should not be attempted since the

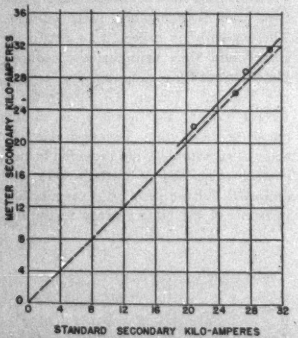


**Figure 8. Comparison of current-crest-meter measurements with simultaneous secondary-shunt measurements as a standard**

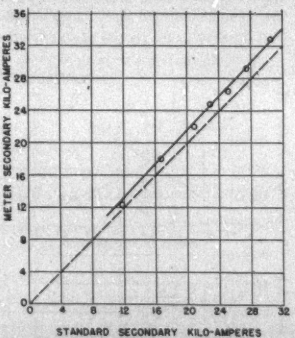


**Figure 9. Comparison of pointer-stop-ammeter measurements with simultaneous secondary-shunt measurements as a standard**

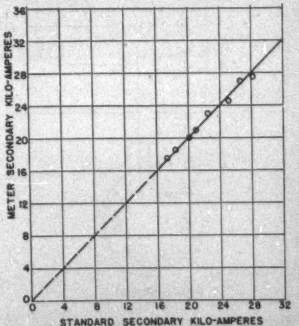


**Figure 10. Comparison of vacuum-tube voltmeter measurements with simultaneous secondary-shunt measurements as a standard**

maximum rate of change of welding current, which the meter actually measures, is only simply related to effective value for sinusoidal currents. Calibration and use of the meter requires that the critical voltage of the lamps remain constant with time, a relationship about which more information is needed. In general, experience thus far indicates that further development of this type of meter might prove to be worth while.

## Comparison

Figures 7, 8, 9, and 10 are plotted for comparison of results by different methods. These are plotted using simultaneous secondary shunt measurements with an electromagnetic oscillograph, as a standard of comparison. The dotted curves would represent exact agreement. The solid lines represent the instrument readings. The primary shunt and vacuum-tube voltmeters give excellent agreement. The current-crest meter seems to have an optimistic tendency although the readings are within the limits of experimental error to be expected with this method—that is, about five per cent. The decidedly optimistic tendency of the pointer-stop ammeter is evident in figure 9.

It is hoped that this experience may prove helpful to those who have the problem of measuring such currents, and that it may be an encouragement to others to continue the development of these and possibly better methods of spot-welding-current measurement.

## References


1. G. G. Somerville, General Electric Company, Pittsfield, Mass.

2. L. H. Frost, Thomson-Gibb Electric Welding Company, Detroit, Mich.

3. A New General-Purpose Meter for Resistance Welding, C. Stansbury. The American Welding Society *Journal*, September 1935, pages 32–5.


## Discussion

**C. Stansbury** (Cutler-Hammer, Inc., Milwaukee, Wis.): For several years we have been using the neon-tube type of meter. In our design the two neon tubes, calibrated rheostat, and switch for selecting the range are mounted directly on one side of the case in which the air-core toroid is built. Recent models are arranged so that the toroid can be opened up by means of a hinged construction for convenience in placing it around the welding electrodes or primary conductors. Also in recent models only one neon tube is employed. It has been found that these small neon tubes have a slightly different starting voltage for the two halves of the a-c wave and about the same result in bracketing the reading can be obtained with one tube as with two, with less chance for confusion.

With regard to using this meter on nonsynchronous circuits, although no great precision is obtainable, results sufficiently accurate for most practical purposes can be obtained by making a number of welds and using the highest setting which causes a glow on all of the welds. Welds on which the circuit happens to be closed so as to cause minimum transients correspond to the lowest setting of the instrument for which a glow is obtained. We use the meter in either the primary or secondary circuit as most convenient.

As we are not manufacturing this meter commercially, we have not been able to follow up certain things about which we would like to have more information as a matter of general interest.

Some time ago I had occasion to use the meter in the secondary circuit of a spot welder in which the primary current was controlled by ignitron tubes. These ignitron tubes were not synchronously controlled, but were controlled by a relay timer which caused random completion of the circuit. Under these conditions, the meter could not be used at all in the secondary circuit since the tubes glowed at all positions of the dial. When the meter was connected in the primary circuit, it worked satisfactorily. In using the meter in the primary circuit we ordinarily use a flexible, heavy connector and make several passes through the toroid.

Although I did not have an opportunity to determine the reason for this with an electromagnetic oscillograph as I wished, I did try to do so with a cathode-ray oscillograph. This instrument was so seriously affected by the magnetic field around the welder that I could not get any satisfactory results. As the authors state, the cathode-ray oscillograph is very unsatisfactory around a resistance welder for this reason.

A point which I would like to see brought out clearly, either in an appendix to this paper or elsewhere, is the difference in characteristics between an air-core toroid operating with negligible back ampere-turns and the conventional iron-core current transformer.

**G. F. Gardner** (nonmember; General Electric Company, Schenectady, N. Y.): By drawing attention to the necessity for accurate current measurements in welding, the authors have performed a great service to all who are in any way interested in spot welding. The measurements have evidently been carried out with great care and each method has been given the consideration which it deserves.

In connection with the electromagnetic oscillograph-secondary shunt method, the authors do not state the highest values of current which have been measured in their tests, but it may be of interest to note that measurements have been made on welding machines using similar shunts at currents up to 80,000 secondary amperes.

The electromagnetic oscillograph-primary shunt method is also of definite value. It would seem, however, that if it were to be generally applied, the use of a current transformer might be somewhat preferable to the shunt from the standpoint of ease of application and safety to the operator. Care should, of course, be taken to select a transformer whose limitations are not exceeded.

*Current-Crest Meter.* In considering this and the methods which follow, attention should probably be directed to the quantity which it is desired to measure—either the root-mean-square or the peak value of the current. Granted that it is possible to measure some transients and take account of their influence using this type of instrument, it nevertheless must be borne in mind that its indications are as dependent as any other of the crest measuring instruments upon the peak value of the wave. It was noted with considerable interest that the authors mentioned that such an instrument would be a useful laboratory tool. Experimental samples of such devices have been constructed and it is hoped that one will appear on the market shortly.

*Cathode-Ray Oscillograph—Primary Shunt.* The word of caution regarding the use of this instrument is certainly not out of place. Some of our experience indicates that a reasonable distance for an unshielded instrument may be as much as 40 feet from the welding machine.

*Pointer-Stop Ammeter.* It was gratifying to note the authors' experiences with this relatively simple type of instrument since at this stage of the welding measurements art, it appears that the choice is often between a simple means of current measurement or none at all. As regard the "optimistic" indications, this is not an essential feature of the pointer-stop ammeter and instruments can be so designed that they show but very little, if any, increase in reading due to the conditions mentioned by the authors.

The closing paragraph of the authors' work is especially significant and, in line with this, it may be of interest to mention further work which has been done along this line. A device has been made available known as the weld recorder which will give an accurate indication and record of the ampere-squared-seconds existing for a given weld. If the ampere-squared-seconds are not within preset limits, such as plus or minus five per cent, a bell rings and the machine is automatically locked out. The record will show whether the $I^2t$ is above or below the limits. Nearly 100 of these have been made and have been found to have been very useful in establishing levels for resistance-welding measurements and, although their use has been restricted to comparative work at the present time, there is no reason why they could not be applied where definite values of ampere-squared-seconds are required. Space does not permit a full description of the instrument characteristics here, but it is hoped that it will be possible to publish an article containing this at an early date.

**A. J. Corson** and **E. W. Clark** (nonmember; both of General Electric Company, Lynn, Mass.): This paper is a very thorough and balanced evaluation of several existing methods of measuring spot-welding currents. It is hoped that it will stimulate interest, not only in the improvement of these methods, but in the application of them as well. The following discussion is based on a somewhat similar series of experiments, dur-

ing which a comparison of the secondary shunt and oscillograph was made with the pointer-stop ammeter and the vacuum-tube voltmeter.

Figure 7 shows excellent agreement between the primary- and secondary-shunt readings. The primary-shunt readings were presumably multiplied by the welding-transformer ratio as determined by the voltage method. This indicates an absence of errors due to such causes as saturation of the welding transformer, and varying current distribution in the secondary shunt, for the particular conditions of this test. It is doubtful if these conditions would apply to all welding transformers and all secondary loops. For these reasons, we prefer the use of the current method in determining this transformer ratio using a specially designed current transformer in the welder-transformer secondary since it more nearly simulates operating conditions and also avoids the necessity of measuring very low alternating voltages. Also in the interest of minimizing current distribution errors in the secondary shunt, this device was reduced to a minimum axial length 0.080 inch, as compared to the six-inch dimension described in the paper.

The response characteristic of the pointer-stop ammeter is, as indicated by the authors, somewhat dependent on the duration of the impulse. It would be of interest to know, therefore, what duration was used in determining the curve given in figure 9, also what interval of travel was allowed for the pointer oscillation. It would appear that this characteristic, while definite for an instrument of given design constants, is not universal, and by modification of these constants, improvement could be obtained in accuracy. In the meantime the application of a simple correction curve will result in a highly satisfactory degree of accuracy for all ordinary work.

**W. F. Hess, R. A. Wyant, and A. Muller:** In answer to the implied question in the second paragraph of Mr. Gardner's discussion, the maximum secondary root-mean-square amperes which we have had occasion to measure with the oscillograph and secondary shunt is 40,000 amperes.

Mr. Gardner makes a good point in his third paragraph with regard to the safety of the operator when using a shunt in the primary circuit. Care should be taken to mount the shunt so that there will be no occasion to come in contact with it while the primary circuit is energized, and to bring out insulated potential connections. The substitution of a current transformer for the primary shunt in oscillographic work is open to some objections. The wave forms may be distorted by transient currents produced in the secondary of the current transformer. These may be reduced by careful adjustment of the phase angle of this circuit to coincide with the angle of firing of the main power tubes. This adjustment would be an objectionable added complication. The calibrations involved are more complicated. The selection of a shunt to be used with the current transformer and oscillograph must be carefully made to secure good sensitivity and at the same time to avoid overloading the current transformer. Great care must be taken to insure continuity of the secondary circuit of the current transformer to avoid the hazardous voltages which are produced by an open-circuited current transformer. The more precise current transformers are usually not of the clamp-on type. It is therefore almost as difficult to attach them to the welding circuit as to install a shunt. Phase-angle errors are objectionable when simultaneous measurements of voltage drops and current are desired.

Our experience coincides with that of Mr. Stansbury in that the two electrodes of a single neon tube are as effective as two separate tubes in determining the final setting of the voltage divider which measures the toroid voltage.

In response to the suggestion in the last paragraph of Mr. Stansbury's discussion we offer the following. When a toroidal coil is placed around a conductor carrying an alternating current, a portion of the magnetic field set up by the current will link with the coil and induce a voltage proportional at any instant to the rate of change of the current. The peak voltage which we measure is therefore a measure of the maximum rate of change of current. Only for sinusoidal currents is the effective or heating value proportional to the maximum rate of change of the instantaneous value. Hence only such currents will be correctly measured by the peak value of the voltage developed in a toroidal coil.

A precaution that must be exercised in the use of a toroid is that the voltage must be measured without drawing appreciable current from the winding, since any current taken will tend to distort the flux set up by the current being measured, displacing it from within the toroid and causing the toroid voltage to drop.

In the case of the iron-core current transformer, a current must be permitted to flow in the secondary winding which balances at every instant the magnetic effect of the primary current. If such a secondary current does not flow, the flux density in the core will tend to rise and the secondary current will no longer be proportional to the primary current. Also the primary winding and iron core will act as a choke coil or reactance in the power line, and will absorb large energy losses from the line which it is incapable of dissipating. On the other hand if the resistance of the secondary circuit is kept sufficiently low, so that the current-transformer core does not saturate, then the current in the secondary will be a direct measure of the primary current even with considerable departure from sinusoidal wave shape.

In reply to the discussion of Messrs. Corson and Clark, the transformer ratios used in calculating secondary current from primary readings were, as stated in the body of our paper, determined by voltage readings. It is true that for the comparison tests presented in the paper the magnetizing currents were so low as to be negligible, indicating the absence of any approach to saturation of the welding transformer. Before using any method involving primary-current readings we have recommended the measurement of magnetizing currents for all settings of the welding transformer. If the magnetizing currents are found to be appreciable, as they may be on the higher taps of the transformer, the primary readings should be corrected for magnetizing current, before applying the transformer ratio to calculate the secondary current.

If the transformer core is approaching saturation, as evidenced by relatively high magnetizing current, there will be an error in determining the transformer ratio by voltage readings, due to primary leakage impedance. The voltage drop due to this impedance should be subtracted from the applied primary voltage to obtain the primary voltage induced by the mutual flux, which latter should be divided by the secondary open-circuit voltage to obtain the true transformer ratio. Owing to the difficulty of measuring the separate primary leakage impedance, another approach to the determination of transformer ratio is preferable. For those welding-machine connections which give rise to appreciable magnetizing current at rated voltage, the primary and secondary voltage readings should be taken with the primary voltage at such a reduced value as will avoid an excessive magnetizing current. The turn ratio may then be calculated from these readings without appreciable error.

The use of primary and secondary current transformers to determine the transformer ratio involves the use of special costly equipment not readily available, and would appear to involve at least as much chance for error in the two transformers and accompanying meters as should be expected with the voltage method. We have found no difficulty in measuring the low alternating voltages, with a good laboratory instrument. The axial length of the shunt used for secondary current measurement was approximately three-quarters inch between potential connections. The total length of manganin in the secondary circuit was about one inch. The six-inch dimension mentioned in our paper was the length of the manganin cylinder used in the calibration measurement to determine resistivity.

The duration of current flow for the curve given in figure 9 was six cycles. It had been determined that no definite reduction in reading occurred until impulses of less than four cycles duration were used. The interval of travel allowed for the pointer oscillation was approximately $^1/_{100}$ inch, which was about the minimum definitely perceptible.

# Vector-Response Indicator

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THE performance characteristics of a communication circuit are often conveniently described in the form of a response curve which indicates the steady-state transmission of the circuit at frequencies within the range of interest. These curves can be obtained by making a sufficient number of individual measurements of transmission at various frequencies within the band of interest and plotting the results; however, considerable time may be saved by the use of a device which indicates directly the desired curve. Many such response-curve tracers are found in radio laboratories,

Figure 1. Comparison between elliptical-trace and reference-point methods of phase-angle measurement

Figure 2. Reference-point method used for a direct-reading high-frequency phase-meter

with the curve of transmission or amplification as a function of frequency being obtained as a trace on a cathode-ray tube. However, strictly speaking, the transmission of a circuit, being the ratio of output voltage to input voltage of the same frequency, is a vector quantity having an angle as well as a magnitude—the angle being the phase angle between the output voltage and the input voltage. The response-curve tracers now in general use indicate only the magnitude of the amplification as a function of frequency. The vector-response indicator described in this paper is a unique apparatus that indicates directly both the magnitude and phase angle of the transmission as a function of frequency. This vector response of the circuit is indicated by a special type of pattern on the screen of a simple cathode-ray tube.

Some of the new communication systems recently developed have brought about an appreciation of the importance of phase characteristics. For accurate reproduction of a complex voltage wave the circuit must have, over the range of frequencies present in the wave, the properties that the magnitude of the transmission is constant and the phase angle is a linear function of frequency with the intercept at zero or $n\pi$. Except with circuits of long time delay, such as long telephone lines, little or no thought need be given to the phase characteristic requirement in sound circuits, since the ear is not sensitive to moderate phase displacements. However, in television and facsimile systems the complex wave shape must be preserved for acceptable reproduction, and this means that the desirable characteristics must be preserved in both magnitude and phase.

Phase-angle measurements above audio frequencies can be made from the elliptical trace produced on a cathode-ray tube screen when the two sine-wave voltages to be compared are impressed on the horizontal and vertical deflecting plates respectively. The phase angle can be calculated from measurements of the geometry of such a trace. If the phase angle were to vary periodically, as might be caused by a periodic variation of frequency, a series of elliptical traces would be produced, but this trace on the cathode-ray-tube screen would not indicate in a direct manner the variation of phase angle as a function of frequency.

For the vector-response indicator, it was necessary to develop a new method for measuring phase angles, which would give a more direct indication of the angle. This new method differs from the elliptical trace method in that one of the two voltages to be compared is applied to the vertical deflecting plates, the other voltage being used to give a reference pulse which is applied to the control grid of the cathode-ray tube. The reference pulse is obtained from some particular point in the cycle, such as the positive peak; this reference pulse is applied to the grid with such polarity that it causes the beam to

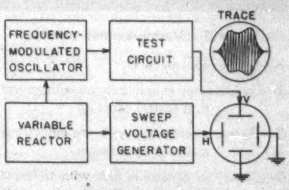


Figure 3. Simplified block diagram of a response-curve indicator

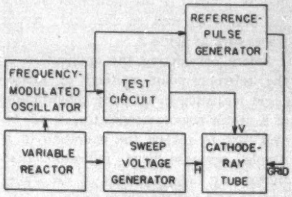


Figure 4. Simplified block diagram of a vector-response indicator

become brighter. With a linear sawtooth sweep applied to the horizontal deflecting plates, the sine-wave trace of the voltage on the vertical plates is seen, together with a bright spot at the instant that the other voltage reaches its positive peak (or other reference point). Thus, the location of the spot along the trace is a direct indication of the phase angle between the two voltages. Figure 1 shows a comparison between the ordinary elliptical trace and the reference-point methods for several phase angles.

If no sweep voltage is applied to the horizontal deflecting plates, the trace will be merely a vertical line with a bright spot on it; the location of the bright spot indicates the phase angle between the voltages. An appropriate scale might be placed alongside this line and the phase angle read off directly. This is one way of using the reference point method to make a direct-reading high-frequency phase meter. However, to make the exact location of the spot along the line more evident, the pulse voltage

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**Figure 5. Vector-response patterns**

*A*—Simple resonant circuit

*B*—Double-tuned coupling circuit with greater than critical coupling

*C*—Three-element circuit with one inductance and two capacitances

*D*—Similar to preceding but with different ratio of capacitances

may be applied to the horizontal deflecting plates as well as the grid, giving traces such as figure 2.

Before considering the application of the reference-point method of phase-angle measurements to the construction of a vector-response indicator, it will be well first to review the operation of a simple response-curve indicator that shows only the magnitude of the transmission and not the phase angle.

If a constant sine-wave voltage is applied to the input of a circuit under test, the amplitude of the output voltage, with respect to the input voltage, indicates the transmission of the circuit at that frequency. If further, the frequency of the input voltage is slowly varied, but its amplitude always kept constant, then the variation of amplitude of the output voltage indicates, in some manner, the variation of transmission of the circuit with frequency (that is, the response curve). By varying the frequency periodically, and applying the output voltage to the vertical deflecting plates of a cathode-ray tube, a vertical trace, whose length varies periodically, will be produced. Then by applying a sweep voltage of the same period as the frequency variation to the horizontal deflecting plates, the variation of the length of the trace will be visible. The result will be a trace, symmetrical about a horizontal axis, whose envelope indicates the response curve of the circuit over the range of applied frequencies. Figure 3 shows a simplified block diagram for such a response-curve indicator.

The simple response indicator just described can be easily made into a vector-response indicator by a circuit addition. By adding a circuit which derives a pulse at some reference point in the cycle of the voltage applied to the input of the circuit, and then applying this pulse to the grid of the cathode-ray tube, an indication of the phase angle is obtained (figures 4 and 5). The trace produced now has a bright line appearing within the envelope of the trace. At any abscissa, the relation between the ordinate of this bright line and the ordinate of the envelope indicates the phase angle of the circuit at the frequency corresponding to the particular abscissa. If the reference pulse is obtained at the positive peak of the input cycle, then when the bright line coincides with the top envelope, the output voltage is in phase with the input. When it coincides with the lower envelope, they are 180 degrees out of phase. It may be desirable at times to have a 90-degree leading phase angle indicated by coincidence with one envelope and a 90-degree lag by coincidence with the other envelope. This can be accomplished by producing a 90-degree phase shift between the voltage applied to the test circuit and that applied to the reference pulse generator.

**Figure 6. Vector-response patterns for a band-pass amplifier with a double-tuned input circuit and a single-tuned output**

*A*—Proper adjustment of all circuits

*B*—Similar to *A* with single-tuned circuit tuned above mid-band frequency

*C*—Insufficient loading in double-tuned circuit

*D*—Similar to *C* with single-tuned circuit tuned below mid-band frequency

*E*—Less than critical coupling in double-tuned circuit

*F*—Similar to *E* with single-tuned circuit tuned above mid-band frequency

A simplified block diagram of the vector-response indicator is shown in figure 4. The variable reactor can be a motor-driven variable capacitor, or a reactance tube, that is, a vacuum-tube circuit arranged to appear like a reactance. The sweep oscillator is synchronized with the variable reactor so that they have the same period. A simple reference-pulse generator might be a vacuum-tube biased beyond cutoff to such an extent that plate current flows only at the positive peak of the applied alternating voltage.

Some illustrations of traces obtained on a vector-response indicator using simple circuits are shown in figure 5. It will be noted that in figure 5*C* there are two zero power factor frequencies, while in figure 5*D* the circuit has capacitive reactance at all frequencies. Figure 6 shows results using a band-pass amplifier with one double-tuned coupling circuit and one single-tuned circuit operating at 175 kc.

All the oscillograms were photographed directly from a small cathode-ray tube (type 902) having a screen of two inches diameter. The apparatus constructed for these tests differed from the simplified block diagram of figure 4 by the use of a beat-frequency signal generator instead of a simple oscillator to generate the desired signals. Properly designed

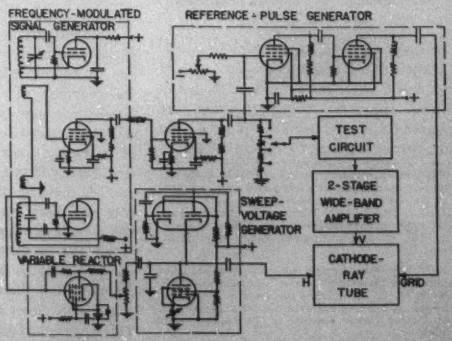


**Figure 7. Circuit diagram of vector-response indicator used in tests**

# Causes of Corrosion of Fine Copper Wires Carrying a Potential

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COPPER CORROSION is a serious problem in electrical equipment which uses very fine wires carrying a potential, the outstanding examples being various types of coils used in radios and ignition systems. The usual type of corrosion involves the formation of green material on the surface of the wire, which is obviously due to chemical reaction of the copper with materials in contact with it. As this chemical reaction progresses at a given point in the wire, the cross section of unchanged copper gradually diminishes until finally a break occurs, opening the circuit and rendering the coil useless.

## Previous Views of Copper Corrosion

In the past, the question of the actual cause or causes of copper corrosion has often been approached by means of inference rather than experiment, and it is, therefore, not surprising that widely varying views have been held by different people. Probably one of the most popular beliefs is that free acids in materials contacting the wires are responsible. This belief has been the basis of specifications of "acid-free" papers and tapes to be used in the construction of coils. In some cases, specifications are given which require that a distilled water extract prepared by some standardized technique must fall within certain limits of pH. More recently it has been recognized that acids are not the only substances which might cause this effect. Assuming that electrolysis is the fundamental cause of corrosion, it would follow that not only acids but also bases and salts would produce the same effect.

Another similar view is based on the idea that the rate of corrosion of copper wires in contact with a given material is proportional to the conductance, or inversely proportional to the insulation resistance of the material in question.

Again, it has been a common observation that copper corrosion is most serious in high humidities, and this fact has given rise to the belief in some quarters that moisture absorption is the primary factor in corrosion.

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## Corrosion by Adhesive Tapes

The present study was primarily concerned with the causes of corrosion by adhesive tapes used in the fabrication of coils, and although the results have implications of broader significance, we shall first deal briefly with the specific problem which prompted this work.

Adhesive tapes may be considered as a combination of two functional parts, the adhesive and the backing. We may conveniently consider these in order.

At the present time, electrical-tape adhesives are mainly of the rubber-resin type, although in the past, glue has been used. The use of the latter may be disposed of rather summarily, as it is now known that glue hydrolyzes rather rapidly in high humidities at elevated temperatures, with the production of organic acids of sufficient activity to be a major cause of corrosion. The ill-advised attempts to correct the difficulty by using dialyzed glues, which could be made substantially electrolyte-free, resulted in only a transitory improvement; because in use, the glue itself was a source of electrolytes.

## Experimental Study of Corrosion

In view of the fact that corrosion by the more satisfactory electrical tapes developed so slowly under any practical operating conditions, it was necessary to develop an accelerated corrosion test. We therefore canvassed the radio industry, and finally standardized on a test similar to the most severe ones in use. The arrangement consists essentially of two parallel bare copper wires at a potential difference of 90 (later increased to 250) volts direct current held under tension against the surface to be tested, under conditions of 90 per cent relative humidity and 120 degrees Fahrenheit. The specimen was placed on the bowed surface of a moulded block with two binding posts at each end and was held in position by two parallel bare copper wires, spaced $^3/_{16}$ inch apart and each held under slight tension by a pair of binding posts. Originally, number 40 wires were used, but later it was found more satisfactory to use number 32 wires and estimate the amount of corrosion microscopically. At 90 volts, the usual duration of the test was four days.

Glues, however highly purified, were found in this test to be highly corrosive. Purification delayed slightly the beginning of corrosion, but did not result in an important improvement.

The rubber-resin type of adhesive, on the other hand, is not a cause of corrosion, provided that reasonable care and common sense is used in its formulation. The usual adhesive made from rubber, rosin, and zinc oxide also yields, during artificial aging which would correspond to at least five years of natural aging in the absence of light, products which contribute nothing toward corrosion. Thus, in spite of the fact that the very term, "acid", to the layman, is the symbol of death and destruction, we find that an adhesive which contains a large percentage of abietic acid is noncorrosive. Abietic acid and similar resin acids are so weak and so difficultly soluble in water that their acid properties may be neglected.

## Corrosion by Cellulosic Backings

The elimination of the adhesive as a factor in copper corrosion by pressure-

amplifiers were added where necessary. Figure 7 shows the circuit diagram of the apparatus.

## Conclusion

An apparatus has been described that is believed to be new and useful. From the ideas presented there can be developed various phase measuring equipment, such as direct-reading high-frequency phase-meters, phase-characteristic indicators, phase-curve tracers, and time-lag-curve tracers, as well as the vector response indicator described. The increasing use of television and frequency modulation systems should make phase-measuring apparatus such as these of increasing importance in circuit investigation and testing.

**Table I. Insulation Resistance at 120 Degrees and 90 Per Cent Relative Humidity**

| | Megohms | |
|---|---|---|
| | Unextracted | Extracted |
| Rayon (viscose) | 3 | 112 |
| Linen | 4 | |
| Silk | 20 | 4,000 |
| Wool | 1,700 | 1,400 |
| Cellulose acetate | 5,000 | 10,000 |

sensitive tapes leaves the backing as the remaining possibility. At first it was assumed that impurities in the paper or cloth were responsible, and we therefore tested a wide variety of papers ranging from cheap wrapping papers through purified papers for electrical uses, and finally, the most highly purified alpha-cellulose obtainable, in the form of ash-free filter paper. The extracts of these various papers, prepared according to ASTM standard *D*-202-34T, section 45, showed large differences in both pH and electrolytic conductivity, but although the low-grade papers caused very bad corrosion, we were surprised to find that there was no significant difference in this respect between the most highly purified alpha-cellulose and any good saturating paper. The inference was plain that the cellulose itself (in the presence of water) was causing corrosion, but we were at first so reluctant to accept this conclusion that we attempted to purify the cellulose further by exhaustive extraction, in a syphon extractor, with highly purified water. An additional extraction with highly purified ether was performed in some cases. However, all such purified samples behaved similarly, and there was no noticeable improvement over the unextracted samples. A similar study of the effect of purification on cotton fabrics yielded exactly parallel results.

Now, if cellulose itself, in the presence of water is a source of copper corrosion, cellulosic materials other than paper or cotton ought to show the same behavior. We therefore studied samples of linens and viscose rayons, all free from loading or sizing materials, and we found that they caused corrosion at essentially the same rate as cotton or paper. Regenerated cellulose films such as are used as the base for Cellophane behaved in the same manner. Furthermore, we found that exhaustive extraction of any of these materials as in the case of paper, produced no perceptible improvement. Other fabrics made from natural fibers, such as silk and various kinds of wool, were also found to cause corrosion, but wool was very much superior to all other natural fibers in this respect. Again, it was obvious that impurities were not responsible because exhaustive extractions failed to produce any improvement. It is rather surprising that silk is not much better than cellulose in the matter of corrosion whereas wools, which are also protein fibers, are very much better than either silk or cellulose.

## Noncorrosive Materials

The elimination of paper and all fabrics made from natural fibers then led us to search for a synthetic material which would be free from corrosive nature. Briefly, it has been found that there are a number of materials which are satisfactory from a chemical viewpoint; for example, cellulose esters and ethers, rubber and some of its derivatives, and a number of synthetic resins from the polymerization of styrene, vinyl derivatives, or methacrylates. Of the above materials, cellulose acetate is the most economical to use and the one with the best mechanical properties; consequently it is the only one which has been exhaustively tested over long periods of time. It has been tested both in the form of transparent sheets and in the form of cloth woven from the fibers, and apparently is completely free from tendency toward copper corrosion. There is every indication that a fine copper wire in contact with cellulose acetate will last as long as one suspended freely in air.

## Possible Causes of Corrosion

After having been compelled to recognize the fact that cellulose itself was a source of corrosion, the next step was to inquire into the reason and several possibilities were investigated. One obvious possibility, to which reference has already been made, is that the corrosive nature of a given substance is a function of its absorptive (or adsorptive) capacity for water. Only a cursory examination of the facts, however, is sufficient to show that this is not so. Wool shows a much higher moisture absorption than cotton, yet is far superior with regard to freedom from corrosive nature. Also, cellulose acetate shows a moisture absorption which is reported to be over half as great as for cellulose itself, yet it is completely free from corrosive nature.

If corrosion is fundamentally due to electrolysis, a flow of current would necessarily be involved. Conductivity (or its reciprocal, insulation resistance), ought therefore to parallel the rate of corrosion by various test samples. Accordingly, a series of measurements was made on fabrics of approximately 0.006 inch thickness as nearly alike as possible in density of weave, and all free from loading and sizing materials. The specimens were mounted on binding posts $1\frac{1}{2}$ inches center to center, and were conditioned for 48 hours at 120 degrees Fahrenheit and 90 per cent relative humidity before measuring resistance under those conditions. A parallel series of measurements was then made on the same fabrics after they had been exhaustively extracted with highly purified water. We believe that the results are sufficiently striking to merit including them (table I).

A glance over the trend of the insulation-resistance values for the unextracted samples might seem to indicate that the real explanation of corrosion was to be found here. However, when we pass on to the values for the extracted samples, we find that the enormous increases in resistance for rayon and silk completely refute the idea that corrosion parallels insulation resistance. For example, a 20-fold, or more, increase in insulation resistance by extraction results in no appreciable decrease in corrosive nature. There still remained the possibility that insulation resistance might decrease rapidly during the period of the corrosion test, but this was shown not to be so. It seemed impossible that the corrosion process could be independent of any flow of current, but our results indicated clearly that flow of current in itself was not the controlling factor.

## Electrochemical Oxidation as a Cause of Corrosion

As a last resort, we attempted to test the possibility that electrochemical oxidation of cellulose, in the presence of water, might take place at the anode, and we were finally rewarded with the correct explanation of the observed copper corrosion. If the cellulose were oxidized at the anode, water-soluble organic acids would be formed and ought to be capable of detection. For test purposes, it was necessary to replace the copper wires by some metal which would not react with such acids. We therefore used platinum wires in contact with rayon and carried out the test in other respects exactly as the standard corrosion test described above. At the end of six days, the specimen of rayon was examined for chemical changes in the cellulose. By means of Harrison's reagent[1] it was found that the cellulose had acquired reducing properties throughout the whole area between the wires, indicating either hydration or

oxidation. By means of indicators, it was shown that free acid was present only along a thin line which had been in contact with the positive wire. It is a commonplace fact that green copper corrosion always appears on the positive wire. Hence, the production of water-soluble acids at the anode offers an explanation of this corrosion which appears to be inescapable. Incidentally, it can readily be demonstrated on a large scale that cellulose is electrochemically oxidized to a complex mixture of water-soluble organic acids. By grinding up cellulose fibers and suspending them in water in an oxidation cell, large quantities of these acids may be obtained.

The above explanation of corrosion also offers an obvious explanation of the failure of exhaustive extraction to reduce appreciably the corrosive nature of paper or cellulose fabrics. If appreciable amounts of water-soluble acids are formed by the oxidation of cellulose, the presence or absence of traces of electrolytes in the original paper or cloth is quite unimportant. Therefore, as far as corrosion problems are concerned, extremely rigid specifications on paper or cloth probably do not accomplish anything useful. This does not imply, of course, that any low-grade material is just as good as a highly purified one, but merely that there is a definite limit to the usefulness of purification. The initial presence of large amounts of electrolytes is, of course, bound to have an effect.

Only in the case of cellulose has it been possible, by means of sensitive tests, to demonstrate under conditions to which radio coils are normally exposed, what actually takes place during the development of corrosion. The development of corrosive properties in protein materials may be largely or even altogether due to hydrolysis instead of oxidation. One might, therefore, tentatively specify as a noncorrosive material one which is nonelectrolytic itself and which is (*a*) resistant to oxidation and hydrolysis or (*b*) yields nonelectrolytic products.

Rubber is an example of the latter type, whereas the cellulose ethers and esters are quite resistant to oxidation. Apparently all that is necessary to increase enormously the resistance of the cellulose molecule to oxidation, is to replace the hydroxyl groups. It appears to be quite immaterial whether they are replaced by the acetate, nitrate, or any one of various other groups; the result is always a great increase in resistance to oxidation. Thus we find that any one of these cellulose derivatives is apparently satisfactory as far as corrosion is concerned, although cellulose acetate is the only practical possibility at the present time.

## Mechanism of Copper Corrosion

During the corrosion of copper wires under a potential, the fundamental change that takes place is the oxidation of metallic copper to cupric ion ($Cu - 2e = Cu^{++}$). If we designate the negative ion which appears in combination with $Cu^{++}$ as $A^-$, the compound may be written as $CuA_2$. The latter accumulates as a green cupric compound on the positive wire. The two prerequisites for the appearance of green corrosion are, therefore, oxidizing conditions at the copper wire and availability of a negative ion. It is obvious that the deficiency of electrons at the positive wire provides the oxidizing conditions, and if an electrolyte is present in the path between positive and negative wires, all that remains is to provide mobility for its ions. At high humidities, water which is absorbed, or adsorbed, by cellulose provides the medium in which the ions may migrate. In low humidities, that is, in the virtual absence of free water, corrosion is, in general, exceedingly slow.

It is obvious that the presence of any electrolyte which will yield $A^-$, will contribute toward the formation of the green product of corrosion, $CuA_2$. It is immaterial whether the electrolyte is an acid, HA, or a salt such as NaA. Thus, pH measurements are without significance in predicting or explaining corrosion, as a neutral salt may be at least as harmful as an equivalent amount of acid. In fact, if we are considering a very weak acid such as abietic acid and its salt, the latter will be much more harmful. The acid itself may be so weak or so insoluble, or both, that it will be practically un-ionized, whereas the salt will be highly ionized. It is a familiar fact that rosin itself has no corrosive action, whereas sodium abietate (rosin size) is highly corrosive.

Now to return to the specific case of cellulose, electrochemical oxidation will take place at the wire at which oxidizing conditions exist; namely, the positive wire. The organic acids formed by oxidation will thus make immediately available their negative ions, and conditions for formation of a salt, $CuA_2$, are complete.

If, however, we examine this mechanism of corrosion critically, we find that in order for corrosion to proceed by deposition of negative ions of organic acids on the positive wire, a corresponding flow of current would necessarily take place. This would require that corrosion be a function of conductivity and would appear to be in direct conflict with our finding that samples of cellulosic fabric, extracted and unextracted, respectively, show no correlation between rate of corrosion and conductivity. This conflict, however, may be apparent rather than real, for the reason which follows.

Suppose we examine two samples of cellulose fabric, one contaminated with a trace of active electrolyte and one exhaustively purified. The initial insulation resistance of the former will be greatly decreased, particularly in high humidities, by the presence of electrolyte; but one might expect that with continued application of potential, the electrolyte would be used up and the insulation resistance would rise to approximately that of the previously purified sample. This is actually what we observe experimentally. In addition, the disappearance of the contaminating electrolyte would leave the cellulose itself as the only remaining source of corrosive material, and one would expect that the continuing rate of corrosion would approximate that of the previously purified sample. Thus we see that the amounts of corrosion caused, respectively, by purified cellulose with a high insulation resistance and by material contaminated by electrolyte, will differ only by the corrosion caused by the contaminant. This might well be so small as to be unimportant.

## Impregnation as a Protection for Corrosive Materials

In view of the high cost of cellulose-acetate films and cloth, it would be highly desirable to use paper or cotton as a base material for tape backing and impregnate or coat with some noncorrosive material. A number of attempts have been made to develop a practical construction of this type, but the result has been consistent failure. It must be borne in mind that a satisfactory material for the purpose must be sufficiently tough so that contacting wires will never penetrate the film of impregnating or coating material and come in contact with the cellulose. Such noncorrosive materials as paraffin, shellac, and other highly thermoplastic or excessively brittle materials are obviously inapplicable. Cellulose acetate itself is satisfactory, but as a matter of experience, such a heavy coat is required to give complete protection of the surface, that no economic advantage could be gained. In addition, when such material was slit, cut, or torn, cellulose fibers were exposed,

thereby generating a region at which corrosion could take place.

To sum up, we feel that the most satisfactory and practical construction for a corrosion-free electrical tape is cellulose acetate coated with a good quality rubber-resin adhesive.

### Reference

1. Society of Dyers and Colorists *Journal*, volume 28, 1912, page 359.

## Discussion

**B. W. Erikson** (General Electric Company, Schenectady, N. Y.): H. N. Stephens and G. B. Gehrenbeck are to be congratulated on their masterly and timely solution of a very difficult problem. It is well-known to anyone who for years has been connected with the manufacturing problems incident to fine-wire coils that so-called corrosion failures have constituted the majority of all field failures.

The successful use in recent months of so-called noncorrosive material has plainly indicated that the writers have correctly analyzed the causes for fine-wire corrosion failures. Coils operated on an accelerated test at 100 per cent humidity in 40 degrees centigrade ambient over periods of months have conclusively proved that if the ordinary cellulose materials such as tapes and papers are excluded from the coil structure and acetate, mica, or asphaltic materials substituted the coils will last practically indefinitely. As a comparison, coils made with the best so-called acid-free cellulose materials on these accelerated tests seldom last beyond ten days, whereas the so-called corrosion-free coil construction shows a life expectancy of at least four months under these very severe tests. Our tests agree with the authors' that moisture is an essential factor in corrosion failures.

In relation to the paragraph on impregnation as a protection of corrosive materials it has been quite definitely shown that even three or four coats of a good baking varnish is not enough to protect against fine-wire corrosion. For this reason we agree with the authors that the only really satisfactory solution is the strict adherence to corrosion-free materials or in other words the exclusive use of cellulose acetate, mica, and asphaltic materials.

**G. B. Gehrenbeck:** Mr. Erikson lists three materials which he considers as corrosion free; namely, cellulose acetate, mica, and asphaltic materials. When tested across a flat unbroken surface, mica is indeed noncorrosive. However, when the test is made between two edges or along one edge, we have found rather low resistivity and some evidence of corrosion. Apparently, some electrolyte is present between the laminae of the mica, which under high humidity may carry an appreciable current. In a coil, there is always the possibility that the fine wires will come in contact with the edge as well as the face of the insulation. On this basis, mica appears to be less desirable for the insulation of fine wire coils than does cellulose acetate.

# Contact Phenomena in Telephone Switching Circuits

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**Synopsis:** The phenomena occurring at the closing and opening of contacts carrying weak currents have been investigated by means which include a study of the high-frequency transient voltages and currents. These influence the erosion in a complex manner which varies with contact materials, surface conditions, and surrounding atmosphere. Three principal classes of effect have been distinguished. These are: (1) Disruptive spark-overs initiating a series of metallic arcs lasting less than a microsecond each. (2) A nitrogen-gas glow discharge at about 300 volts, preceded by a brief group of disruptive spark-overs. (3) High field breakdowns due to cold point discharges which cause transient metallic closures of approaching contacts and similar transient reclosures of separating contacts.

THE operation of a telephone system depends on the proper performance of many millions of electrical contacts, a large proportion of which are in relays. The relays must be designed for a life during which they operate from as few as 5,000 to as many as 400,000,000 times. Although the nominal currents and voltages carried by the contacts are rather low, the large number of operations may cause erosion which in a very small percentage of cases leads to failures to close or open the circuit. The difficulties caused by even very rare failures make the control of contact erosion a problem of major importance for the telephone companies.

Research and development work on contacts has of course been carried on continuously since very early in the development of the telephone system. The aim is to design contacts to have a life at least equal to that of the apparatus of which they form a part and to require a minimum of maintenance. Although this aim has in general been successfully met there have been some cases in which the contacts have worn out too rapidly.

Although it has long been realized that contact operation necessarily involved the generation of high-frequency transients, there was at first no apparatus available which would permit these transients to be studied. The Dufour oscillograph was for a long time the only instrument which covered the range of frequencies involved. It was employed as early as 1926 in studies of contact sparking but it was very cumbersome in use, often introduced artificial conditions into the circuit of the contacts, and progress with its use was necessarily very slow. During the past few years rapid advances have been made in the development of glass-envelope cathode-ray oscillograph tubes. By employing the latest types of tubes, and combining them when necessary with wide-band high-frequency amplifiers and with circuits which permit synchronization of the tube sweep circuit with the contact operation, it has been possible to make thousands of observations in the time originally taken by a single oscillogram, and to cover the entire range of currents, voltages, and frequencies involved. We now have available means which will permit the visual observation of transient voltages at frequencies as high as 400 megacycles per second, and transient currents with components reaching 20 megacycles per second. Single pulses lasting a small fraction of a microsecond, and complex transients containing components as high as 5 megacycles can be clearly resolved and photographed while the envelopes of still higher frequencies can be recorded.

In order to study the transients at contacts operating at 50 volts and steady currents under one ampere, in common types of telephone circuits, voltages as high as 2,000 and currents reaching 20 amperes must be within the range of the apparatus. A detailed description of the apparatus will not be attempted in this article, but the results of observations made with it and photographs of the more significant transient components will be presented.

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The author wishes to acknowledge the collaboration of E. T. Burton in the observation and explanation of the phenomena and the assistance of I. E. Cole in the development of the testing apparatus; of Mr. Glass, who developed the cathode-ray tubes; and that of many engineers and physicists in our organization, in particular Messrs. Mathes, Hogg, Goucher, and Pearson, in the formulation of some of the hypotheses expressed.

Study of the currents requires an amplifier as an impedance matching device and some circuit conditions make a shielded input transformer necessary. An input impedance of from 0.5 to 2 ohms, a voltage gain of about 75 times, and a substantially flat characteristic of output versus input from 20 kilocycles to 20 megacycles are usually employed. Lower frequencies may be observed with other amplifiers and the range from zero to 10,000 cycles per second is studied by means of the "rapid record" oscillograph.

With earlier cathode-ray tubes, beam currents of 40 microamperes at 5,000 volts were employed. The latest tubes give a beam current of about one milliampere at this voltage. A Leica camera with an $f/1.5$ Xenon lens and ultraspeed panchromatic film has been used in most of the photographic work. The photography is complicated by the presence in a single transient photograph of some components in which the beam speed may be a thousand times as fast as it is in others. However, beam speeds in excess of 200 kilometers a second are position in the entire transient, very high sweep speeds are impractical for photography as a prohibitively large proportion of exposures would be blanks. A sweep speed of about 15 kilometers per second is about as high as is useful except in some special cases.

We may commence the discussion by setting up what appears to be a very simple circuit (see figure 1), a pair of contacts, one of which is connected by a length of wire to a relay winding, which is in turn connected to one pole of a 50-volt battery. The mate contact and the other pole of the battery are grounded by very short wires. The oscillograph is arranged so that the voltage between the contacts and the current through them can be observed, great care being taken to insure that the added apparatus does not appreciably change the circuit characteristics even at very high frequencies. A low-power microscope may be set up to observe the operating area of the contacts.

When the contacts close, the first thing that happens is the discharge of the relay structure (a capacity) and of the ampere occurs, and is over before the steady current through the relay winding has more than started to build up. The frequency of the line oscillation depends on the length and other characteristics of the wire, but it is (in the telephone plant) rarely lower than 500,000 cycles, and on short leads it may be many megacycles. Fortunately most contacts are not much affected by closing a half ampere. Erosion and build-up will occur, but at rather slow rates, and they are usually completely obscured by effects due to the contact opening. Of course, if the contacts bounce,* the effect will be more complex, but we are assuming for the moment that they do not bounce. The structure of the relay itself, including the pair of springs separated at its base by an insulating sheet, is also an oscillating circuit. We have not been able to get inside of this circuit and measure the current surge but its oscillation frequency seems to be about 250 megacycles for certain telephone relays.

Now suppose that the simple circuit of our closing contacts is complicated by an additional wire connected to the

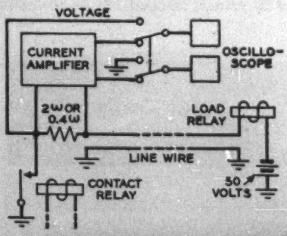


Figure 1 (left). Typical relay and contact circuit

Figure 2 (right). "A" transient starting with metallic arc (voltage)

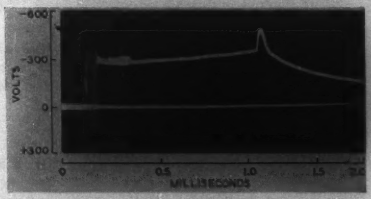


Figure 3. Entire "B" transient (voltage)

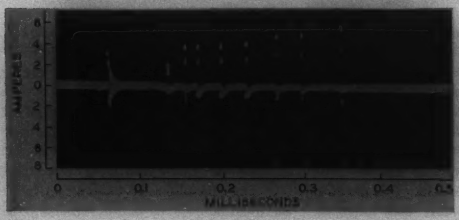


Figure 4 (below). Entire "B" transient (current)

photographed, and a continuous sine wave of 5 megacycles frequency may be clearly resolved on a single transit. Sweep speeds which permit resolution of much higher frequencies are employed for visual observation, where the transient component being studied can be found by frequent repetition of the contact operation. As the occurrence of a particular component varies in time of its wire through the contacts. The wire may be thought of as a radio antenna, more or less open-circuited at the load relay-winding terminal, and either grounded or opened at the contacts. The wire forms an oscillatory circuit of moderately heavy damping with a surge impedance of about 100 ohms. As it is charged to 50 volts, when the contacts come together an oscillation having a peak current of 0.5 contact-spring terminal. This is also charged to 50 volts before the contacts close, and being a second circuit of a hundred ohms surge impedance in parallel with the original wire, the current peak discharged through the contacts will now be about one ampere. But now the contacts are likely to act differently.

* Bounce, as distinguished from chatter, reopens the contacts after several thousandths of a second.

About a microsecond after the current reaches its peak, but before the charge in the wires has been completely dissipated, the circuit is interrupted and the discharge stops. A spark, which is visible in the microscope, suggests that the current-carrying areas have been exploded and blown apart. A few microseconds later they again close and the rest of the energy is discharged, but some of the contact metal must have been destroyed.

If several "idle" wires are attached to the contact, the current surge, and the number and duration of the contact reopenings increase, but not usually in direct proportion to the number of wires. If the idle wires are attached to the load relay-winding terminal instead of to the contact, the current is smaller, as the length of single wire from relay winding to contact is effectively in series with them.

In the telephone relay circuits which we are considering, the steady-state current plays little part during contact closing if the contact-carrying relay is properly adjusted, as the contacts come to rest while the current is still held at a small fraction of its final value by the inductance of the load relay winding.

Under some conditions which are more likely to occur in telegraph than in telephone circuits the contact closure phenomena are somewhat different than those described above. Assume, for example, that the potential between the open contacts may be adjusted in a range between 30 and 250 volts while the final direct current is limited by circuit resistance to less than 0.5 ampere. At the low voltage, observations of the current and voltage transients indicate that the closing contacts merely discharge the line. As the voltage is raised so that the current surge peak is in the range between 0.5 ampere and 1 ampere the reopenings, due presumably to overheating of the contacting areas by the discharge, are observed. These become more frequent as the voltage and current increase, and a new type of current surge begins to appear. This is placed on the time axis ahead of the point at which the initial closures have been occurring (usually five to ten microseconds earlier) and consists of one or more irregularly spaced heavily damped pulses of current lasting only a small fraction of a microsecond and evidently discharging only a minute amount of the energy stored in the system. They occur perhaps once in a hundred closures at 30 volts, nearly every closure at 100 volts, and several for every closure at 250 volts. It is believed that the transients observed indicate the formation of minute metallic bridges[1] between the approaching contacts due to a softening of the metal by a cold point discharge and its deformation by the static field, and that once formed they are exploded by the discharge of current from the relay structure and adjacent wiring. The high fields necessary for phenomena of this type are of course due to the minute distances as the contacts approach final closure. A good deal of the erosion on telegraph-relay contacts operating on capacitative loads or shunted by resistance-capacity "spark-killer" circuits is probably due to these "preclosures," but they are not thought to be of much importance at the lower battery voltages of the telephone plant.

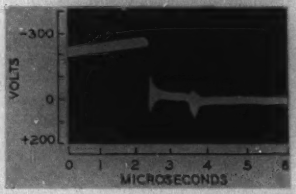


Figure 7. Initial opening and reclosure—"B" transient (voltage) rapid sweep

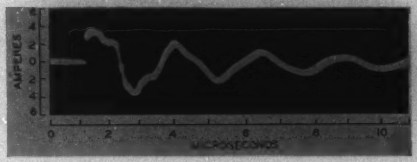


Figure 8. Initial opening and reclosure—"B" transient (current) rapid sweep

Figure 5. Initial opening and reclosure—"B" transient (voltage)

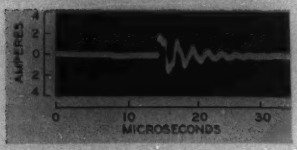


Figure 6. Initial opening and reclosure—"B" transient (current)

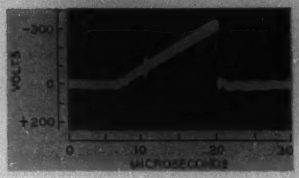


Figure 9. Evidence of point discharge (voltage)

Having now described the phenomena as contacts close in a doubtless oversimplified manner, we may consider that they have been closed for a long time, the direct current and the magnetic field of the load relay are established, and the contacts are to be separated. The action now becomes really complicated and much of it is as yet only surmised. Several different things may happen, and these are influenced by humidity, dirt, surface films, absorbed gases, and many other factors, including the speed of contact separation, the roughness of the surfaces, and the presence or absence of a wiping motion as well as the physical properties of the contact materials.

If the steady current exceeds certain well-known values ranging between 0.4 ampere and 1 ampere, characteristic of the contact materials, a metallic arc is formed as the contacts separate.[2] This is maintained at an initial potential of about 15 volts, and increases to a final value usually below 30 volts. The arc may last several milliseconds, but when it breaks it is followed by a complex transient lasting possibly another millisecond. These transients may be of two general types to be described later. This case is not of much importance in the telephone plant as the steady current is ordinarily kept below the value at which prolonged arcing occurs.

Metallic arcs lasting several ten-thousandths of a second, and also followed by complex transients, may occur in breaking steady currents considerably less than those ordinarily believed to cause arcing. The effect of these transient

1. For all numbered references, see list at end of paper.

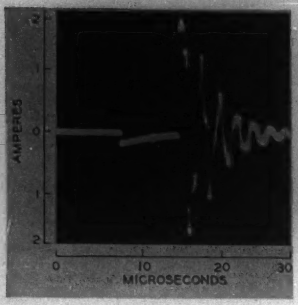


**Figure 10. Evidence of point discharge (current)**

arcs on contact life has not been studied separately, but they can hardly fail to increase the erosion. Their effect is unavoidably included in the studies of contact life in the higher range of d-c values. Figure 2 shows the voltage between a pair of opening silver contacts in which the steady current (0.25 ampere) is strong enough so that a brief metallic arc (indicated by the upward deflection of the trace to a new horizontal position) precedes the final transient.

If the steady-state current is low enough so that neither prolonged nor brief metallic arcs are formed at the initial contact separation, one of two general types of complex transients occur, or both types may be mixed. These have been designated the *A* and *B* types. The *B* type transient seems to be the more normal and it is difficult, probably impossible, to set circuit and contact conditions which will never give a *B* transient. It is identified by a bright spark between the contacts, showing in a spectroscope bright lines of the vaporized metal, and consists of a series of disruptive spark-overs at gradually increasing voltages. Each spark-over is individually very complicated. The appearance of the contacts during the *A* type transient is radically different from that during the *B* transient. There will be a minute bright spark, surrounded by a violet cloud which spreads out from the immediate contact area over the negative contact, and sometimes travels as far as a sixteenth of an inch from the working area.

As a result of thousands of observations of the transient currents and voltages, and many experiments, and discussions with several physicists and engineers with whom the writer is associated, a plausible explanation of the phenomena has been arrived at and will be given as at least a working hypothesis.

The voltage wave form of an entire *B* transient, covering the time from the initial separation of the contacts to the final subsidence of the voltage charging the line wire is shown in figure 3, and the a-c components of the current in the range from 20 kilocycles to 20 megacycles are shown in figure 4. The low-frequency components of the current are comparatively weak. A line and load relay were chosen to give a relatively simple transient with the important components at frequencies which could be photographed. A 500-ohm Western Electric U-type relay and a line of 300 feet of number 22 switchboard pair were used. The mate wire of the pair was grounded at both ends. The currents and voltages were not photographed simultaneously but the types of the transients were correlated by repeated observations. A current picture will not exactly correspond to a voltage picture, as the transients produced by successive operations of a contact are never identical.

The *B* transient may be explained as follows, using as a basis the simple circuit of figure 1. The steady current is established and the contacts start to separate, moving apart at a speed, which is at first surprisingly slow (about an inch a second). The contacts have been deformed by the pressure between them, and as this is relaxed, the current density and the temperature at the contacting areas rapidly increase until at some light pressure the area becomes so small that the current explodes it. There may be some necking out of the softened contacts before this and under some conditions there are indications of a metallic arc lasting a fraction of a microsecond, but at any rate, an initial rupture occurs between hot and soft metal areas.

The wire has been at ground potential, but the battery plus the collapsing magnetic field of the load relay commence to charge it at a rate depending on the line and relay-winding capacity and the relay inductance and losses. In 10 or 20 microseconds, it has reached at the contacts a potential of from 50 to 200 volts. This is below the voltage at which spark-over due to ionization of the air can occur, but something usually happens which recloses the circuit. This is believed to be caused in somewhat the same manner as the "preclosures" mentioned earlier. It is probable that a cold point discharge reheats the contacts. This is followed by a collapse of the voltage to about 15 volts above zero in the direction of the previous voltage, indicating the formation of a metallic arc. This lasts a fraction of a microsecond and the voltage then drops to nearly zero, suggesting that the contact areas heated by the field current and the arc have been drawn together in solid metallic contact. The line is discharged with an oscillation of comparatively low damping (which is characteristic of the line wire) reaching a current peak usually ranging from 0.5 to 2 amperes. The first cycle of the oscillation is distorted by the higher resistance of the path to ground caused by the arcing stage in the reclosure. After a few microseconds the

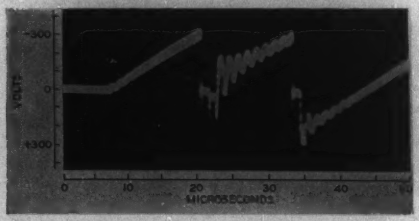


**Figure 11. Early part of "B" transient (voltage)**

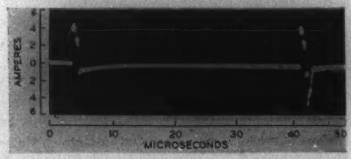


**Figure 12 (right). Early part of "B" transient (current)**

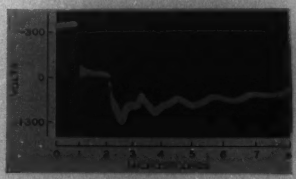


**Figure 13. Single spark-over of "B" transient with single arc (voltage)**

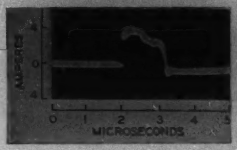


Figure 14. Single spark-over of "B" transient, with single arc (current)

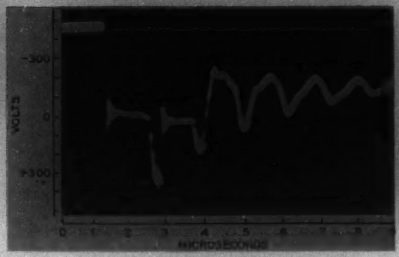


Figure 15. Single spark-over of "B" transient, with double arc (voltage)

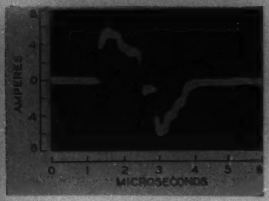


Figure 16. Single spark-over of "B" transient, with double arc (current)

contacts are opened a second time by the continued motion. Occasionally they reclose a second time but they usually stay open until the voltage has built up by the continued discharge of the load relay inductance to a value between 300 and 350 volts. Then a spark occurs at what is usually considered the minimum sparking potential between contacts in air.

Figures 5 and 6 show the voltage and current of the initial opening and reclosure of the contacts at the start of a *B* transient. The brief arc at initial opening is barely detectable in figure 5. Figures 7 and 8 show similar voltages and currents at an increased sweep speed. In figure 7 the metallic arc established during the reclosure is plainly evidenced by the collapse of the voltage to about 15 volts and its maintenance at this value for about a microsecond before it drops to zero. The effect of the arc in distorting the oscillating discharge of the current from the line wire is evident in figure 8. The current oscillation of figure 8 may be duplicated merely by charging the line wire to a suitable voltage through a high resistance and closing the contacts, the far end of the line being grounded through the load relay and a large capacitor which replaces the usual battery.

It is likely that the point discharge precedes the arc on reclosure by such a short time that it cannot ordinarily be resolved. Nevertheless disturbances of the voltage and current are occasionally found which seem to indicate that a discharge path formed and was checked (possibly by melting off the point) without establishing an arc or metallic bridge. Such a disturbance of the rising voltage is indicated in figure 9 by a high-frequency oscillation about five microseconds after the first rise of the voltage trace. Figure 10, which shows the current of the second of two initial reclosures, indicates a similar phenomenon. Five microseconds after the rupture of the circuit, shown by the downward deflection of the zero line, a dim line upward records a current surge lasting a fraction of a microsecond and reaching about three-fourths ampere. This surge however did not result in the immediate formation of an arc which was established about five microseconds later.

The initial separation of the contacts does not always result in a metallic reclosure. Figure 11 shows the voltage of the early part of the *B* transient. Here the first collapse of the voltage is a spark-over from about −300 volts which establishes an arc at about −15 volts. This arc is broken and as the line is not completely discharged, the voltage between the contacts rises to about +140 volts; a second arc is established at +15 volts and broken in its turn. Possibly because of the continually increasing distance, the arc is not re-established, and the voltage builds up with oscillations of a frequency characteristic of the line wire insulated at both ends until it reaches −300 volts a second time and another spark passes. This time only one arc is formed, and the recovery of the voltage starts from the positive side of the zero axis. The current surges corresponding to the voltage collapses of figure 11 are shown in figure 12. Here the first pulse represents a spark-over which formed only one arc. As the current from the line reached about four amperes it was checked and the conducting arc was broken (possibly by being extended laterally into the region of cooler metal). The second pulse shows the current of a spark-over which formed two arcing periods.

These phenomena are shown in more detail in figures 13 and 14 which show the voltage and current of a spark-over forming only one arc, and 15 and 16 which show the wave forms when two arcs are formed. Note that the frequency of the current oscillation is that of the line grounded at one end only (the impedance of the load relay being high at this frequency) and is about half that of the voltage oscillation which is that of the line open at both ends. Oscillations of both frequencies may be found in the line at a distance from either end.

Corresponding observations may be made of the occurrence of 3, 4, and 5 arcing periods, the pattern followed being about the same. The higher the voltage at spark-over the more arcing periods;

Figure 17 (left). Typical "mixed A and B" transient (voltage)

Figure 18. Effect on voltage transient of changing wire-line length —1,100 feet

an odd number of arcing periods is followed by a recovery of the voltage from the opposite side of the zero axis from that of the voltage before spark-over, an even number by recovery from the same side of the zero axis. The arcing periods are individually complex, having superposed on them oscillations believed to be due to the relay structure and the leads to the oscillograph which are too fast to be resolved photographically by the means available. These oscillations may be observed visually by using higher sweep speeds and reach frequencies of 250 megacycles.

While the arcs ordinarily do not exceed a microsecond in duration, they are probably an important factor in determining contact erosion, as several hundred may occur at each contact opening.

As may be seen from figure 3, the spark-overs continue to occur, the successive voltage breakdowns corresponding to the normal sparking potential as the contact separation increases with time (with some irregularities due to residual ionization in the gap) until the separation is finally so large that the energy remaining in the load relay cannot charge the line to the breakdown voltage. At this stage the line discharges slowly back through the load relay to the battery voltage. The peak voltage reached may be as high as 2,000 volts.

The principal characteristics of the *B* discharge can be produced by a simple experiment which does not use a load relay. The transient is not dependent on a load inductance, but only on a source of voltage which will charge a wire at a sufficiently rapid (but not too rapid) rate while a pair of contacts, which initially ground the wire, are separating. If a wire about 100 feet long is connected to a source of somewhat more than 350 volts through a resistance of from 5,000 to 20,000 ohms, and is also grounded by a contact at one end, a transient is produced when the contacts open which shows the characteristics of a *B* type transient except the final dying away of the voltage to 50 volts.

It must not be understood that every spark transient is purely of either the *A* or the *B* type. It is very common for the *A* type transient to break down into the *B* type and less often the *B* transient establishes the gas glow discharge for a brief period in the middle of the spark-overs.

A "mixed" transient is shown in its entire duration in figure 17. Here, after a group of spark-overs, a period in which the voltage is maintained steadily at about 300 volts for about 0.0002 second intervenes, and is followed by more spark-overs from considerably higher voltages. In order to produce this transient the length of the line wire was reduced to ten feet, at which length and with a 1,000-ohm load relay the tendency is to produce intermittent groups of *A* or *B* transients, interspersed with the mixed type shown, when the relay is operated frequently.

The number of spark-overs in each *B* transient varies with the circuit conditions. As many as a thousand may be found with a load consisting of a number of relays in parallel on a wire of moderate length and as few as one in the limiting case.

While the occurrence of the *B* transient is favored by long line wires and high-impedance relay loads, beyond a certain length which with telephone relays and wiring is from 300 to 2,000 feet (the longer lengths being associated with the lower impedance relays) no spark-overs at all occur. The voltage build-up is so slow that the spark-over potential is not reached at any time during contact opening and the contacts may be said to be protected by the line wire. The series of voltage oscillograms, figures 18 to 24 inclusive, shows the change from a smooth transient with no spark-overs through the *B* type with an increasing number of spark-overs to the final *A* type. The *A* type transient of figure 22, which has superposed on the 300-volt gas glow discharge stage a relaxation type of oscillation, the *B* transient of figure 23 and the simple *A* transient of figure 24, were all produced under identical conditions in quick succession. The change in characteristics from figure 18 to figure 24 was produced merely by a

**Figure 19 (left). Effect on voltage transient of changing wire - line length—600 feet**

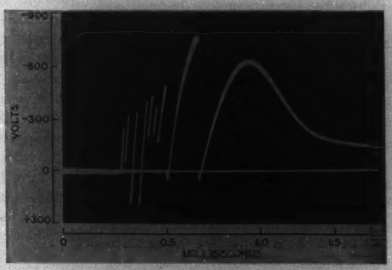


**Figure 20 (right). Effect on voltage transient of changing wire-line length—150 feet**

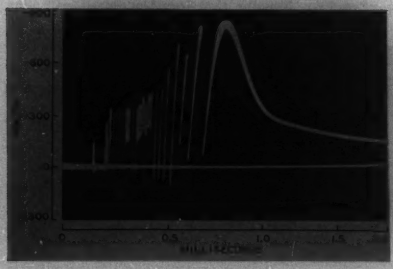

**Figure 21 (left). Effect on voltage transient of changing wire-line length—50 feet**

**Figure 22 (right). Effect on voltage transient of changing wire-line length—10 feet**

reduction in the length of the connecting wire from 1,100 feet through three intermediate stages to 10 feet, a 1,000-ohm load relay being used. This explains a puzzling effect noted with many contact

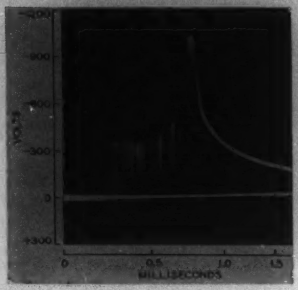


**Figure 23. Effect on voltage transient of changing wire-line length—10 feet**

materials. With a supposedly identical circuit, the erosion will be small with very short wires, increase rapidly as the wiring length increases, and then decrease again becoming very small with very long wires.

The *B* transient is more frequently observed with freshly filed contacts, at high humidities, and with a rolling or wiping motion of the contacts in opening. It is always found if the contacts are of oxidized metal or operate in an oxygen atmosphere. In fact, there seem to be good reasons for believing that its production is bound up with the presence of oxygen on or in the surface of the active contact metal.

It may be seen from the last series of oscillograms that if the circuit and the conditions of the contact surfaces are just right, the *B* transient is replaced by a much simpler and less stable type, the *A* transient. It will occur usually when the wiring is short or the load relay is of low impedance, with contacts which have been operated until the original surface has been burned off and have not stood idle more than a few minutes. It starts much as does the *B* type, but after a dozen or a hundred spark-overs from about 350 volts, which come much closer together in time than those of the *B* transient, the voltage becomes steady at about 300 volts. This condition lasts for perhaps 0.6 millisecond, then the voltage rises to about 400 or 450 volts and gradually reduces, reaching the battery voltage after several milliseconds. A typical *A*-type transient is shown in figure 24. It is suggested as a hypothesis that during the spark-over stage, the oxygen is being exhausted from the surfaces of the current-carrying areas of the contacts by burning the metal and that when this has been completed, a nitrogen-gas glow discharge is formed and maintained during the rest of the contact opening, if the supply of energy from the load inductance through the line is rapid enough to prevent the voltage from dropping below about 280 volts.

The glow-discharge phase of the *A* transient is unstable. If transient voltages induced by the operation of relays in other circuits reach the contact gap during the time that a sustained glow discharge is attempting to form, its formation is interfered with and a mixed or *B*-type transient results. Occasionally as illustrated in figure 22 the glow discharge of the *A* transient has superposed on it a saw-toothed oscillation of from 10 to 50 volts peak-to-peak. Part of an *A* type transient showing this peculiarity is illustrated by the oscillogram of figure 25. This appears to be a relaxation oscillation such as is commonly produced in ionized-gas tubes, riding on the normal 300-volt axis of the gas glow discharge. The conditions which lead to the occurrence of this oscillation at atmospheric pressure have not been identified, but it is found to be quite stable in some cases where contacts have been sealed in a mixture of air and gases at about half atmospheric pressure.

A typical *A* transient is shown in detail in figures 26, 27, and 28. The circuit consisted of a 250-ohm relay connected to the contacts by ten feet of wire, the battery being 50 volts as usual. Figure 26 shows the voltage of the early part of the transient during which rapid spark-overs are interspersed with two brief periods during which a gas glow discharge was established but not maintained. Figure 27 shows the final spark-over before the establishment of the glow discharge at about 300 volts. A group of the current pulses corresponding to the initial part of the spark-over stage is shown in figure 28. These are complicated by the line oscillations (which should be of about 30 megacycles frequency) and appear to last less than 0.1 microsecond.

It may be seen that the individual spark-overs at the start of the *A* transient are somewhat different in form from those of the *B* transient. The voltage reaches 320 volts in a microsecond or so, and in some cases collapses to zero or beyond immediately. There are sometimes indications of arcing periods lasting much less than 0.1 microsecond and the voltage recovers with oscillations of the line wire but the duration of the phenomenon is too brief for very accurate analysis. But in many cases, the voltage having reached its peak, drops to an intermediate value of 280 volts and recovers to 320 volts before it collapses. This is probably due to the temporary formation of the nitrogen glow discharge, which is finally established and maintained during the remainder of the contact opening when for some reason the spark-over does not occur. In cases where the contacts are on the verge of producing a *B* transient the voltage may rise to 500 volts and then collapse to the 300 volts of the gas glow discharge.

It is very interesting to set up a circuit which will cause the *A* transient to predominate, and start operating freshly filed contacts several times a second observing the transient voltage at contact opening on the oscilloscope. The first transient will always be of the *B* type. Usually the first few dozen will also. However, after a while one of the transients will show a flat top at about 300 volts for a very brief period and this tendency increases until finally a complete *A* transient occurs. After this, the *A* transients become more and more com-

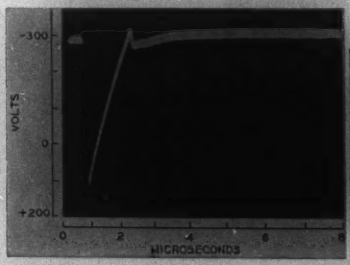


**Figure 24. Effect on voltage transient of changing wire-line length—10 feet**

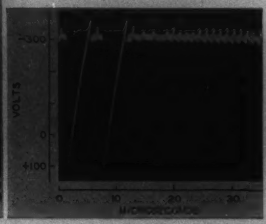


**Figure 25. Oscillation on glow discharge of "A" transient (voltage)**

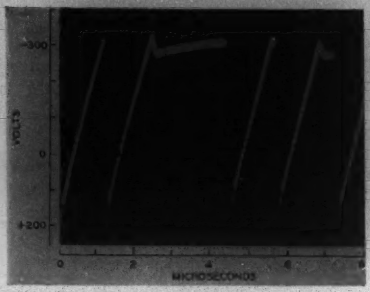


Figure 26 (left). Start of "A" transient (voltage)

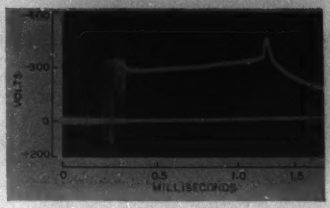


Figure 27 (right). Start of stable glow discharge of "A" transient (voltage)

mon until finally the *B* transients occur perhaps once in a hundred openings. If then a gentle stream of oxygen is blown on the contacts, only *B* transients will occur until a few seconds after it has been turned off. Blowing the breath on the contacts has a similar but less definite effect, while a stream of dry compressed air has no effect.

If on the contrary the circuit conditions are selected so that *B* transients predominate, a stream of nitrogen will induce *A* transients. That is, *A* transients are not found in oxygen and *B* transients are rare in nitrogen.

If instead of operating the contacts several times a second they are operated at longer intervals, the tendency to produce the *A* transient is reduced. When contacts are operated in air a certain interval between operations can be found which causes all transients to be of the *B* type. This probably depends on humidity and also on circuit conditions and contact material. In one experiment, a wait of 45 seconds between operations gave all *B* transients with silver contacts, while a wait of five minutes was required with palladium contacts. This is possibly due to a different rate of film formation.

Life tests on palladium contacts show much lower erosion with *A* transients than with *B* transients. The effect of the two types of transient in terminating the life of silver contacts is not markedly different. The contours of the eroded surfaces exhibit a wide variety, and it is not easy to correlate the transient type with its effect. It is evident, however, that areas of the contacts which have never been in the d-c path may be severely eroded.

When we consider that the *B* transients produce oscillations in the line wires reaching several hundred volts and often 15 amperes, it is not to be wondered at that clicks will be produced in circuits in the immediate neighborhood of unprotected relay contacts. The *A* transients produce much weaker currents than the *B* transients and many contacts on successive operations will produce *A*, *B*, or mixed types. This explains the common observation that relay clicks vary over a wide range of amplitudes. The arrangement of telephone circuits in which the cabled wiring always contains a large number of grounded conductors, and is often enclosed in a lead shield, prevents any appreciable free radiation of the spark transient oscillations.

With the foregoing information available the contact erosion process at opening contacts appears briefly to be as follows. At very minute separations high field strengths exist even for moderate voltages. The resulting cold point discharge is often followed by a metallic arc which softens a tiny point on the contact which is pulled out and fused into metallic contact under the action of the high fields. After rupture by increasing separation or increasing current density, the process may repeat or, as is more likely, the separation is too great for another metallic bridge to form. The high field discharge then sets the stage for the next type of conduction or breakdown. This may be either a series of spark-overs interspersed with metallic arcs of extremely short duration or a gas glow discharge, initially intermittent and then more or less stable. Factors predisposing toward one or the other type of discharge are known thus far only in a most general fashion and much remains to be done before the relation between contact erosion and the transient currents and voltages can be predicted accurately. There is ample evidence that molten metal may be expelled from the immediate contact area at high velocity and may be deposited at distances of at least 0.1 inch. It also appears that both the ionized nitrogen cloud of the *A* transient and the disruptive sparks of the *B* transient may corrode the contacts and their supports at locations and distances which never enter directly into the rupture of the current path.

We have seen that the line wire contributes to the current surges through contacts due to its properties as an oscillatory circuit, charged repeatedly by the energy stored in the magnetic field of the relay. The surges and the resultant erosion may be reduced in several ways. If a radio-frequency choke coil is connected between the contact and the line wire, the discharges of the latter are much reduced, and the *A* type gas glow transient favored. A group of many current surges of 15 amperes peak may in most cases be reduced to one or two of 0.15 ampere or less, and a radical reduction in erosion secured. Unfortunately choke coils are expensive and inconvenient. The usual line wire may be terminated in approximately its surge impedance by shunting both ends to ground with a resistance of about 100 ohms in series with a capacitor of the order of 0.01 microfarad. This heavily damps the line oscillations and greatly reduces the number and severity of the current surges. It is also expensive. Instead of the copper line wire, a material such as iron or Permalloy-plated copper having a high surge impedance and large high-frequency a-c losses may be used. This seems more practical, but brings up new problems in design, handling, and soldering.

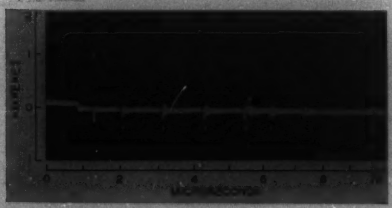


Figure 28. Start of "A" transient (current)

The most effective means of reducing erosion is of course the well-known "spark-killer" (consisting of a capacitor and resistance in series, shunted across the contact or load), which can be designed to hold the voltage below the spark-over point at least until the contacts have separated a safe distance.

When the conventional spark-killer is used it is generally assumed that what sparking then occurs is due to the discharge of the capacitor when the contacts close, provided that the spark-killer prevents the voltage at contact opening from reaching 350 volts. Unfortunately the "reclosure" effect described earlier appears unless the initial rise of voltage as the contacts separate is held down to a value considerably below the sparking potential by a suitable choice of the resistance in series with the spark-killer capacitor. If the rate of increase of the initial voltage in relation to the speed of separation of the contacts exceeds a figure which seems to depend on the contact material and the condition of its surfaces, the high-field point discharge comes into play and causes the separating contacts to reclose metallically while they are still at a minute separation and moving apart very slowly. In "reclosing" the line wire and capacitor are discharged, the current explodes the minute metallic bridge, producing a visible spark, and the circuit is thus reopened. This may occur a dozen times in some cases before the contacts finally stay separated. The higher the voltage which the spark-killer permits the more likely are the reclosures to take place, and the larger the number of reclosures at each contact opening. However, reclosures are usually not very common in cases where the voltage of the wave front is held below 50 volts. In the majority of cases in the telephone plant it is possible to do this without incurring much of a penalty due to erosion of the contacts on closing by the discharge of the spark-killer capacitor.

This discussion is not more than sufficient to serve as an introduction to the problems of contact sparking as revealed by the improved observing technique used in this study. Only the simplest cases have been considered, and the telephone plant is far from being simple. Many relays have multiple windings or metal sleeves, and multiple connections to the contacts are very common. As these complications considerably modify the contact spark wave form and erosion, each contact with associated circuits presents its own problem. The solution of these problems involves the careful study of circuit characteristics of a type which are ordinarily left to the radio engineer, as well as of the mechanical, chemical, and metallurgical properties of the contact materials.

## References


1. The Formation of Metallic Bridges Between Separated Contacts, G. L. Pearson. *Physical Review*, volume 56, September 1, 1939, pages 471–4.

2. Minimal Arcing Current of Contacts, H. E. Ives. Franklin Institute *Journal*, October 1924.


## Discussion

**E. E. George** (Phoenix Engineering Corporation, New York, N. Y.): The paper under discussion contains considerable material of a fundamental nature. This subject apparently has not been discussed previously before the AIEE. The paper answers many questions but raises many more and it is to be hoped that further work on the same subject will be published in the future.

Various relay engineers working with high-speed relays or with long cable circuits for pilot-wire protection or remote control, have run into numerous difficulties resulting from transient phenomena. It would be interesting to know whether the author has found any effect on relay operation other than contact deterioration. It seems that sensitive high-speed telegraphic relays should be affected by the transient currents observed by the author. In power-relay practice, a neon lamp with a high series resistance is frequently shunted across open relay contacts to act as a circuit monitoring device. It would be interesting to know the effect of this lamp on contact operation. It would also be interesting to know whether there is a critical maximum battery supply voltage or length of circuit beyond which trouble is likely to be experienced on pilot-wire circuits.

This paper may explain some of the difficulties frequently observed in trying to use very small d-c supervisory currents on pilot-wire circuits—currents under ten milliamperes.

The author makes reference to so-called "spark-killer circuits" consisting of a capacitor and series resistance, and it would be helpful to give some formula or basis for selecting the proper values of capacity and resistance for such circuits. In the past, it has been the practice of most engineers to consider contact operation perfect if there were no visible sparking. The author has contributed much to a better understanding of contact operation and his paper might well be required reading for all relay engineers.

**A. M. Curtis:** The principal effect of contact sparking transients aside from erosion is in causing contact sticking and consequent failure of the relay to open its circuit. It is possible to conceive of circuit conditions where the cross fire from a lead through which the steady current and transients of a telephone-type relay flows might cause brief operations of a very sensitive relay connected to another lead in the same cable. The principal difficulty from the contact sparking transients would be expected in cases where the induced currents reached the sensitive relay through a rectifier and particularly if the latter should be of a type where the very strong but very brief induced currents might be stored and discharged more slowly. It is hard to make a mechanical relay operate on a pulse only a thousandth of a second long.

A neon lamp shunted across relay contacts gives considerable protection, particularly if the series resistance is not too high. However, this is not as good as a proper spark capacitor as the delay in breakdown of the gas lamp may be 50 to 100 microseconds. During this period the voltage between contacts usually rises high enough to permit several spark-overs.

There is a complicated relation between contact material and battery voltage which has an important influence on the performance of contacts, especially those which work into capacity loads or are protected by capacity spark-killers. Generally it pays to keep the voltage low. Many contact materials which work well between 25 and 50 volts will be unsatisfactory at 150 volts.

I do not know of any general formula which can be used to design spark-killers. They fall into two general classes and some simple guiding principles can be stated.

If the steady current through the contact is above the arcing current of the material it is desirable to keep the voltage at the first opening of the contacts below the arcing voltage. This indicates about as large a capacitor as can be afforded and a resistance at least as low as $R=10/I$. But this leads to a situation where the discharge of the capacitor through the closing contacts may do more damage than the arc which is prevented and a compromise must be made by increasing the resistance to a value where the transient arc is no more troublesome than the capacitor discharge. This, of course, depends on the battery voltage and is another reason for keeping it low.

If the steady current is below the arcing value for the contact materials, the resistance for the best performance should be high enough to prevent the capacitor discharge currents through the closing contacts exceeding about one-third ampere, and low enough to limit the voltage at first instant of contact opening to about 50 volts. That is, it should be higher than $R=3E$ and lower than $R=50/I$. The first condition guards against explosive reopening of the contacts at closure; the second avoids reclosures on opening (always assuming a sufficiently large capacitor). But at the higher battery voltages and currents it is not possible to meet both conditions and in these cases a compromise must be again made. The capacitor should be large enough to keep the surge voltage from reaching 300 volts until after the contacts have separated about 0.002 inch. With many relays this takes about a quarter of a millisecond after the contacts have first started to separate. The capacity required varies with the relay. With a high-resistance relay 0.1 microfarad may be enough. One microfarad is enough for the general run of telephone relays but some heavy-duty electromagnets may require several microfarads.

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**Roller-Smith Adds Plant.**—The Roller-Smith Co., Bethlehem, Pa., has transferred its switchboard division to a recently acquired plant in Allentown, Pa., which is now in full operation, according to Joseph D. Wood, president. The air and oil circuit breaker and instrument divisions will remain in Bethlehem. The switchgear division has its own engineering, drafting and assembly departments in the new plant, of which J. E. Bevan is manager. W. S. Swoish, the company's sales manager, will also supervise sales of the Allentown division. Mr. Wilfred A. Clabault, formerly with the Westinghouse advertising department, has been appointed advertising manager of the company, and will also be engaged in sales.

**Appointments and Promotions.**—A. B. Chance is now chairman of the board of the A. B. Chance Co., Centralia, Mo.; F. G. Chance has been elected president; N. A. Toalson, vice-president; J. T. Isbell has been made vice-president in charge of sales, and O. E. Walker, vice-president in charge of production. . . . . Wilson K. Winbigler is in charge of the new Baltimore branch office of the Ward Leonard Electric Co., of Mt. Vernon, N. Y. The office is located in the Hearst Tower Building. . . . . G. E. Hunt has been appointed manager of the Cutler-Hammer, Inc., Indianapolis office, at 307 N. Pennsylvania Ave., and O. P. Robinson has been added to the sales engineering staff of the Pittsburgh office. . . . . Chester H. Lang, manager of General Electric's advertising and sales promotion activities since 1932, has been named manager of apparatus sales and vice-chairman of the company's apparatus sales committee. He is succeeded by Robert S. Peare, president and general manager of the Maqua Co., a large printing and engraving concern affiliated with the General Electric Co., at Schenectady. He will also be responsible for the operation of the G-E broadcasting stations. . . . . J. G. Gidley is now manager of sales of General Electric Schenectady section, turbine division. . . . Don J. Murray has been appointed sales manager for General Electric conduit products, and H. K. Smith has been made manager of distribution services and secretary of the distribution committee of the appliance and merchandise department, Bridgeport, Conn.

**Eisler Now Callite Tungsten Corporation.**—The corporate title of the Eisler Electric Corporation, Union City, N. J., has been changed to Callite Tungsten Corporation. The company serves many industries with both materials and equipment for the manufacture of incandescent lamps, neon signs, radio tubes, and other electronic devices, as well as electrical contacts of all types. It has specialized in refractory metals and other alloys, particularly tungsten and molybdenum in the form of rod, sheet, wire, and special shapes.

## Trade Literature

**Resistors.**—Catalog 40, 12 pp. Describes vitreous enameled resistors and rheostats in all ranges; prices are included. Hardwick-Hindle, Inc., Newark, N. J.

**Gear Motors.**—Bulletins 403 and 404. Describe single, double, and triple reduction a-c and d-c gearmotors. Reliance Electric & Engineering Co., Cleveland, Ohio.

**Relays.**—Catalog 7, 24 pp. Describes an extensive line of a-c and d-c relays and solenoids. Relay types include transmitter, overload, time-delay, interlocking, mercury-contact, counting unit, etc. Guardian Electric Mfg. Co., 1622 W. Walnut St., Chicago.

**Transformers.**—Cat. Sec. 44-100, 16 pp. Describes a complete line of dry type transformers, auto-transformers, boosters, and phase changing transformers from 1 to 50 kva, for application where space limitations and insurance regulations prohibit the use of oil insulated apparatus. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

**Product Directory.**—Bulletin B6057, 32 pp. Lists 1,610 different and widely diversified products, including descriptive engineering literature and bulletins available on 280 power, electrical, and industrial machines. Manufacturing plants in seven states are illustrated and district offices in the United States and abroad are listed. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

**Fire Protection Systems.**—Bulletin F-11. A comprehensive description of built-in and mobile carbon-dioxide fire extinguishing equipment especially applicable to electrical apparatus. Tests on transformer oil fires are illustrated. A typical protection layout of a generating station is included. Cardox Corp., 307 N. Michigan, Chicago, Ill.

**Voltage Regulators.**—Bulletin GES-2285, 8 pp. Describes type AIRS voltage regulators, built in ratings from 1.2 to 12 kva, 60 cycles, single phase, and from 120 to 600 volts; available for automatic, manual, and manually controlled motor operation. Lists specific applications and advantages accruing from installations. General Electric Co., Schenectady, N. Y.

**Receiving Tubes.**—Bulletin 1275B, 12 pp. Charts give characteristics data on all glass, glass-octal, octalox and metal types of receiving tubes in numerical and alphabetical order. Classification of the types according to their cathode voltages and their functions are included, as well as socket connections with RMA designations. Commercial Engg. Sec., RCA Manufacturing Co., Harrison, N. J.


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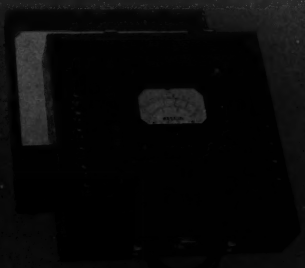
HERE are just five of them. WESTON makes many more. Each designed to meet some particular measurement problem . . . make test procedure simple . . . less time-consuming . . . more efficient. Remember this whenever you are faced with some new or unusual measurement problem. Better yet . . . investigate these WESTON instruments *now* . . . for chances are that one or more will exactly meet your *present* needs. Consult the WESTON representative in your vicinity, or write Weston Electrical Instrument Corporation, 664 Frelinghuysen Avenue, Newark, N. J.



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# New Products

**Electric Current Visualizers.**—Devices recently patented by W. W. Geiser, 4630 N. 11th St., Philadelphia, Pa., show visually, by simulation, both alternating and continuous currents flowing through the windings of the principal types of rotating machines. Three types are available for classroom use, representing a two-phase alternator, a two-phase squirrel cage induction motor, and a four-pole continuous current interpole generator. They are approximately 16½ inches high, 13½ inches wide, and 8 inches deep, with driving motor and lighting self-contained. The transparent dial of each type shows a sort of phantom picture of both stationary and revolving parts, while the current flows realistically through the windings in the proper direction. In addition to the flow of current, some of the phenomena which may be seen includes, in the continuous type (illustrated)

operation of a plain compound wound generator; sparking of the brushes, when moved out of their neutral position, and the cause; shifting of the magnetism, with an increase in the number of lines representing an increased load, and its effect upon commutation; the cause of armature reaction; the introduction of inter-poles and their effect. For synchronous or induction machines the appropriate visualizers are equally effective. For individual use, the three types are reduced to pocket size. They may be held before any source of light and all phenomena studied at the convenience of the student, as slowly as he cares to operate the devices by hand.

**Slot Insulation.**—A new combination slot insulation, made from 100 per cent rag paper combined with Vartex black bias varnished cloth by a special adhesive, has recently been introduced by the New Jersey Wood Finishing Co., Inc., Woodbridge, N. J. This combination slot insulation, termed "Varslot", has unusual flexibility and is highly resistant to moisture and lubricating oils. With greater tearing strength in both directions, the material will stand abuse and will not buckle when placed in a slot. Due to its unusual flexibility, the dielectric strength is not reduced by normal bending and the slot insulation can be cut, slit, or punched without difficulty. It is available in sheet form, continuous length rolls, piece or tape form in any thickness from .012 to 0.26 inch.

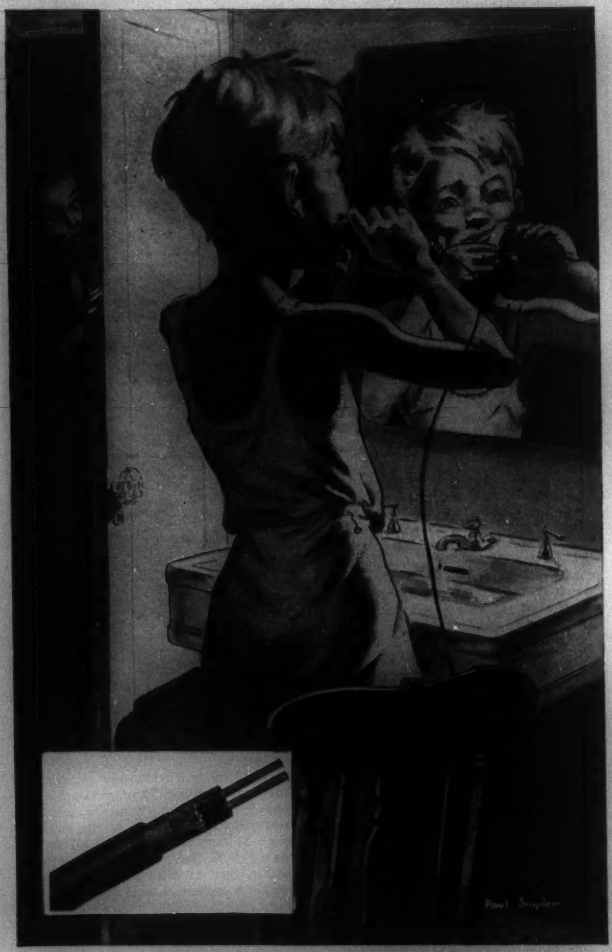
**Portable Voltmeter.**—A new triple range portable voltmeter for industrial and central station use, as well as for all service and

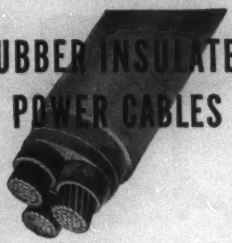
field testing work, has been introduced by Ferranti Electric, Inc., 30 Rockefeller Plaza, New York City. The instrument has been designed for use on a-c circuits and may be employed on d-c circuits with only a slight sacrifice in accuracy. Features of the instrument include—scale length of 5¼ inches; well lighted dial, knife-edged pointer; entirely self-contained; low-priced. Ranges: 0–150/300/750 volts; accurate to ⅓ of 1 per cent; conforms to AIEE and NEMA standards and government specifications. The meter is enclosed in a polished black walnut case, fitted with a hinged cover and heavy carrying strap.

**Portable Printer.**—This "Elpro" portable printer, manufactured by the Ozalid Corporation, Johnson City, N. Y., has been developed for applications where prints are required occasionally. It will make positive type reproductions, in sizes up to 12 by 18 inches, of engineering drawings, maps, letters, reports, and in fact any pencil or ink lines, typewritten or printed matter appearing on one side of a reasonably translucent material. Exposure is accomplished by six specially designed lamps totaling 800 watts. The equipment operates on an ordinary lighting circuit, 110 volts a-c or d-c. A time release switch allows the operator to automatically regulate exposure. The printing operation requires from two to three minutes depending upon the type of original used, and dry development takes between three and five minutes. As many as eight prints can be developed simultaneously.

*(Continued on page 14)*

# *From Portable Cords to*





## RUBBER INSULATED POWER CABLES

**OVER 60 TYPES OF ROEBLING ELECTRICAL WIRES AND CABLES**

Bare Wire and Strand—pigtail, braided copper, trolley

Magnet Wire

Rubber Insulated Wires and Cables:
Building Wires
Service Entrance Cable
Power Cables
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And a wide variety of other wires and cables, either Standard or to Customer's Specifications

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TRENTON, N.J.
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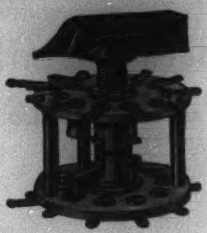
IF IT'S ELECTRICAL WIRE OR CABLE **ROEBLING** HAS IT!

FOR *Permanent* LOW CONTACT RESISTANCE, *use the*

# SHALLCROSS

ROTARY SELECTOR SWITCH



Particularly designed for use with the Thermocouple and other instrument circuits, also to control circuits such as found in high grade electrical apparatus.

Made with a very superior ceramic switch plate known as "steatite," and has *eleven solid "fine" silver contacts and contact arms.* The average contact resistance in this switch is .00075 ohms or less. Supplied with more or fewer contacts, with or without stops, shorting (bridging) or non-shorting.

COST SLIGHTLY MORE—BUT *WORTH MUCH MORE* BECAUSE THEY LAST LONGER, ARE MORE ACCURATE.

Also furnished *enclosed*—mounted on a beveled bakelite panel with etched dial and housed in a cast aluminum box.

These boxes are also available with Shallcross No. 531 Switch, employing brass contacts and phosphorus bronze contact arm.

*Write for Switch Bulletin No. 141-PB*

SHALLCROSS MFG. CO.
*Instruments — Resistors — Switches*
COLLINGDALE, PA.

# New Products

(*Continued from page 12*)

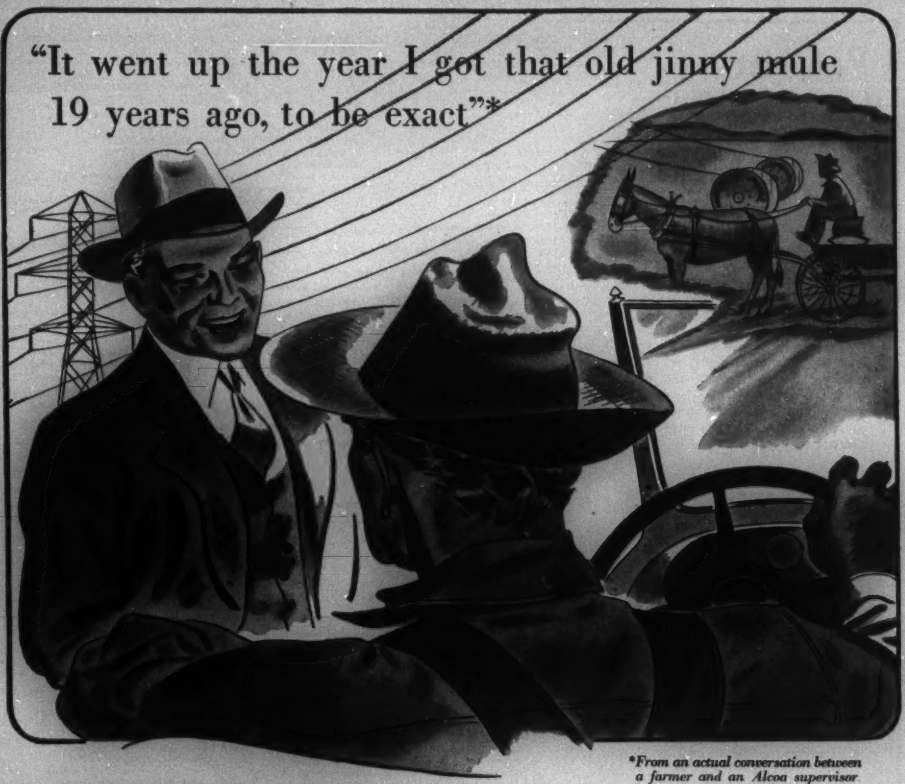
**Pressure Pads for Brushes.**—To offset the injurious effects of vibration on carbon brushes a resilient pressure pad secured to the holder end at the point of contact with the pressure finger has been made available by the National Carbon Co., Inc., Cleveland, Ohio. The use of these pads, where vibration of great severity is encountered, materially reduces and may even eliminate such destructive effects as chipping and cracking of brushes, wear on the holder end of the brush and wear of the pressure fingertip. The resilient material used for these pads is very durable. Within the range of temperatures normally encountered in electrical equipment the pad will retain its resiliency throughout the life of the brush. The form of the pad and its exact location on the brush are dependent on the shape and dimensions of the pressure finger and the location of its contact with the brush. The style illustrated is adapted to a wide range of brush holder designs.

**Sound-Level Meter.**—The type 759-B sound-level meter introduced by the General Radio Co., Cambridge, Mass., is an improved model of the older type 759-A. The new instrument meets the standard specifications for sound-level meters as adopted by the American Standards Association and various engineering societies. It is suitable for use in noise surveys, and for measuring the noise generated by machines and appliances. Features of the new instrument are accuracy, rugged construction, convenience in operation, and portability. A two-speed indicating meter with selector switch is provided. In the FAST position of the switch, the meter speed conforms to ASA specifications. In the SLOW position, the meter is heavily damped and can be used for measuring the average value of rapidly fluctuating sounds. New types of vacuum tubes and batteries give reliable operation and long life. The entire assembly is mounted in portable, airplane-luggage type of case. Batteries are self-contained. The range of the sound-level meter is +24 to +140 db.

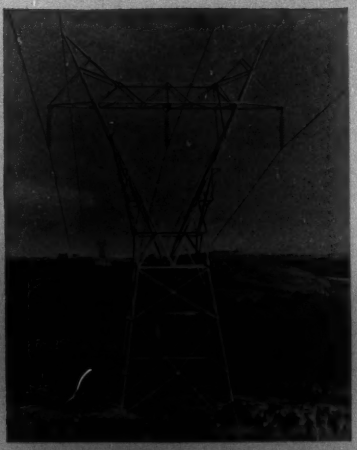
**Paper-Insulated Cable.**—A new type of paper-insulated high voltage cable introduced by the Phelps-Dodge Copper Products Corp., New York, utilizes an improved insulation designed to give the oil impregnated cable longer service life, high impulse strength, and better operating performance. In this cable, known as "Titebilt", a new principle in the design of the layers of paper is employed which eliminates the formation of voids. A carefully chosen proportion of stronger, more highly elastic paper is used for the outer portion of the concentrically applied paper tapes. A means is thus provided of applying a compressing force to the more highly stressed interior of the insulation at precisely the time it is needed, that is, during contraction of the insulation during the cooling phase of its daily heat cycle. The new cables have been under test at the company's laboratories for over five years.

**Test Set.**—The Simpson Electric Co., 5216 W. Kinzie, Chicago, Ill., has introduced a new kit-set, consisting of three small matched meters, in a carrying case. This set is an outgrowth of a new line of nine "Micro-Testers" and is available in combinations to measure current, voltage and resistance for practically any requirement. This grouping of individual meters provides, besides greater flexibility and low cost, much easier reading, according to the manufacturer. Measurements are recorded on separate dials, so that readings can be taken more quickly and with less chance of error than on a single dial, multiple-scale instrument. Any one of the meters may be used separately, or, if necessary, can be replaced. They are not designed to replace panel instruments in production testing, but should be useful for supplementary and portable work. The featured instrument of the new line is "Micro-Tester" model No. 280, a multiple-range a-c ammeter, which is said to mark the first time a current transformer and an indicating instrument have been combined in a small, inexpensive meter; ranges: 0–1, 0–2.5, 0–5, 0–10, and 0–25 amperes.

"It went up the year I got that old jinny mule 19 years ago, to be exact"*



*From an actual conversation between a farmer and an Alcoa supervisor



"That Aluminum line was built in 1921. I remember—"

Many men, like our rural friend, feel a kinship for the "Aluminum" power lines they've grown up with. They boast how "she rode through the winter of the big blizzard." Or recall seasons of exceptionally high winds, excessive heat and cold. These lines earned this respect by staying on the job, year after year, against serious odds.

Men with the power companies have like respect for A.C.S.R. lines. They know that the ability of these conductors to stay on the job means money in their pockets; maintenance costs are low, emergency calls few and far between. That's why, when they're building a new rural or hi-line, they specify A.C.S.R. Their construction follows A.C.S.R. engineering standards.

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*Aluminum Cable Steel Reinforced*

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¶ Limited quantities of pamphlet copies of the technical papers listed, representing surplus stock remaining from recent AIEE conventions and District meetings, are still available.

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**Summer Convention**

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| ☐ 39-111 | Whitehead | The Dielectric Strength and the Life of Impregnated Paper |
| ☐ 39-112 | Race | Dielectric Strength of Insulating Liquids |
| ☐ 39-113 | Race | Tests on Oil Impregnated Paper—IV |
| ☐ 39-116 | Harrison | Ionization Time of Thyratrons |
| ☐ 39-120 | St. Clair* | Multiwinding Transformers with Synchronous Condensers |
| ☐ 39-121 | Marti & Taylor* | Wave Shape of 30- and 60-Phase Rectifier Groups |
| ☐ 39-122 | Lewis & Foust* | Lightning Investigation on Transmission Lines |
| ☐ 39-123 | Alford & Pickles* | Radio-Frequency High-Voltage Phenomena |
| ☐ 39-127 | Benson & Strang | 12-Kv Metal-Enclosed Bus and Switch Structure |
| ☐ 39-129 | Halperin* | Testing of Distribution Arresters |
| ☐ 39-134 | Malti & Herzog | Fractional-Slot and Dead-Coil Windings |
| ☐ 39-136 | Dickerson & Mahan | Painting the Golden Gate International Exposition With Light |
| ☐ 39-137 | Kilitie* | New Type of D-C to A-C Vibrator Inverter |
| ☐ 39-138 | Davis* | Signal System, San Francisco-Oakland Bay Bridge Railway |
| ☐ 39-139 | Hanna & Tritle | Electrical Equipment of the Steam-Electric Locomotive |
| ☐ 39-140 | Reinits & Wiseman* | A New Technique for Lead Cable Sheathing |
| ☐ 39-141 | Smith & Teaney | Temperature Survey of the United States |
| ☐ 39-144 | Aggers, Foster & Young* | Instruments and Methods of Measuring Radio Noise |

**Minneapolis Meeting**

| | | |
|---|---|---|
| ☐ 39-147 | LeClair* | Arc-Furnace Loads on Long Transmission Lines |
| ☐ 39-148 | Summers* | An Unstable Nonlinear Circuit |
| ☐ 39-149 | Foust & Rohats* | Developments in Impulse-Voltage Testing |
| ☐ 39-150 | Peterson, Rudge, Monteith & Ludwig* | Protector Tubes for Power Systems |
| ☐ 39-151 | Fountain, Dissmeyer & Elsi | Co-ordination of Control of Synchronous-Machine Excitation |
| ☐ 39-152 | Maxfield, Hegbar & Eaton | Importance of Gas in Electrodes for Glow-to-Arc Transition |
| ☐ 39-153 | Swanson | Polarized Field Frequency Control of Synchronous Motors |
| ☐ 39-154 | Smith & Boatwick | Ratio Differential Protection of Transmission Lines |
| ☐ 39-155 | Hoard* | Transit-System Modernization, Choice of Vehicle |
| ☐ 39-156 | Bryant & Newman | Electronic Measurement of Surge-Crest Voltages |
| ☐ 39-157 | Bryant & Newman | Measurement of Very Short Time Lags |
| ☐ 39-158 | Butler | Factors Influencing Shunt Capacitor Equipments |
| ☐ 39-159 | Holbrook & Dixon* | Load-Rating Theory for Multichannel Amplifiers |
| ☐ 39-160 | Kurtz | Dynamic Characteristics, Single-Phase Induction Motor |
| ☐ 39-161 | Parsons | Vaults for A-C Secondary Networks |
| ☐ 39-162 | Stephens & Gehrenbeck* | Corrosion of Fine Copper Wires Carrying a Potential |
| ☐ 39-163 | Willey | Emergency Radio as Safeguard to Telephone Service |

**Scranton Meeting**

| | | |
|---|---|---|
| ☐ 39-164 | Renshaw* | Mercury-Arc Rectifiers in Coal Mining |
| ☐ 39-165 | Bell | Lightning Investigation on a 220-Kv System, III |
| ☐ 39-166 | Caldwell | Electrical Apparatus in the Steel Industry |
| ☐ 39-167 | Armstrong* | NEMA Resistors for Motor Starting and Speed Control |
| ☐ 39-168 | Penney* | Temperature Rise of Electrical Apparatus |
| ☐ 39-169 | Compton | Class B Insulation for Auxiliary-Type D-C Motors |
| ☐ 39-170 | Edmunds | Adjustable-Speed A-C Motors |
| ☐ 39-171 | Beavers | Selection of Distribution-Transformer Size |
| ☐ 39-172 | Hentz & Thielman | Power Supply for Suburban Areas |
| ☐ 39-173 | Camilli | Current-Transformer Design |

**Winter Convention**

| | | |
|---|---|---|
| ☐ 40-4 | Torchio | Railway Power Supply |
| ☐ 40-5 | Bellaschi & Palermo | Analysis of Transient Voltages in Networks |
| ☐ 40-6 | AIEE Committee Report | Report on Power Generation |
| ☐ 40-7 | Alexanderson, Edwards & Bowman | Dynamoelectric Amplifier for Power Control |
| ☐ 40-8 | Foust & Scott | Breakdown Tests on Oil-Treated Paper-Insulated Cable |
| ☐ 40-10 | Fisher | The Design Characteristics of Amplidyne Generators |
| ☐ 40-12 | Morgan, Brown & Schuner | Induction Motor Characteristics at High Slip |
| ☐ 40-13 | Morrill | Harmonic Theory of Noise in Induction Motors |
| ☐ 40-14 | Wynne & Woods | The Application of Traction Motors |
| ☐ 40-15 | Noertker | Problems of Electrical Engineering in Transportation |
| ☐ 40-16 | Marti | Static Electronic Frequency Changers |
| ☐ 40-21 | Balsbaugh, Howell & Dotson | Generalized Bridge Network for Dielectric Measurements |
| ☐ 40-23 | Shoults, Edwards & Crever | Industrial Applications of Amplidyne Generators |
| ☐ 40-25 | Lusignan & Miller | What Wood May Add to Primary Insulation |
| ☐ 40-26 | Evans, Gulliksen & Myhre | Synchronizing Transients and Synchronizers |
| ☐ 40-27 | Hill | Power Supply for Railroad Electrification |
| ☐ 40-28 | Craton & Turner | Electric Braking for Railroad and Urban Transit Equipment |
| ☐ 40-29 | Withington | Trends in Railroad Motive Power |
| ☐ 40-34 | Davis & Eddy | Impulse Strength of Cable Insulation |
| ☐ 40-36 | Sporn & Gross | Rationalization of System Insulation—III |
| ☐ 40-37 | AIEE Committee Report | Proposed Standards for Outdoor Bushings |
| ☐ 40-38 | AIEE & EEI-NEMA Joint Report | Recommendations for High-Voltage Testing |
| ☐ 40-39 | Clark | The "Speedomax" Power-Level Recorder |
| ☐ 40-40 | Faucett, Keener & Helm | The Accuracy of Watt-Hour Meters on Intermittent Loads |
| ☐ 40-41 | Goss & Hansen | Rotating Standard for the Measurement of Kilowatt-Hours |
| ☐ 40-42 | Weller, Trekell & Stebbins | Watt-Hour Meter Performance with Power Rectifiers |
| ☐ 40-44 | Bowles, Barrow, Hall, Lewis & Kerr | The Microwave Instrument Landing System |
| ☐ 40-47 | Diamond, Hinman, Dunmore & Lapham* | Upper-Air Weather Soundings by Radio |
| ☐ 40-48 | Loughlin* | The Vector Response Indicator |
| ☐ 40-50 | Milnor | Control of Inductive Interference to Telegraph Systems |
| ☐ 40-53 | Curtis* | Contact Phenomena in Telephone Switching Circuits |
| ☐ 40-54 | Untersee* | Power Requirements of Spinning Frames—II |
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| ☐ 40-69 | Gebelein & Elsi | Analysis of Bushing Current-Transformer Performance |
| ☐ 40-70 | Sinks | Transient Characteristics of Current Transformers |
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| ☐ 40-73 | Pakala & Batten* | Arc-Backs in High-Current Mercury-Arc Rectifiers |
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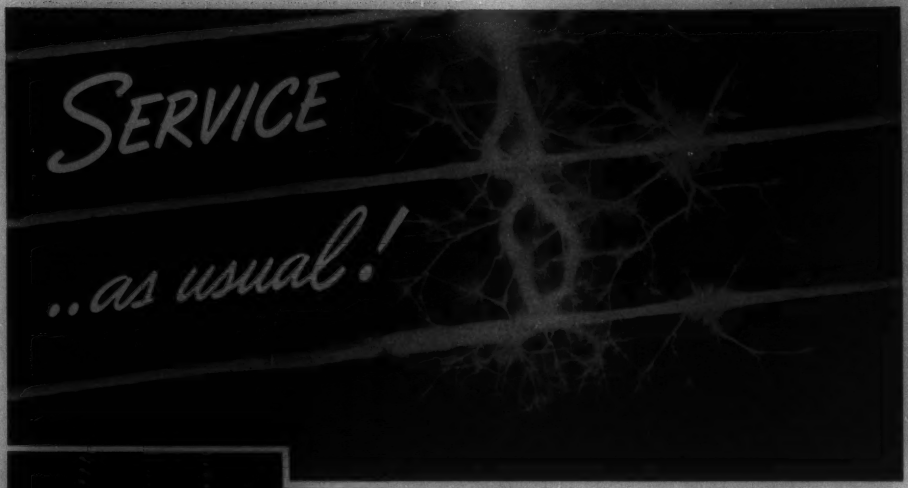
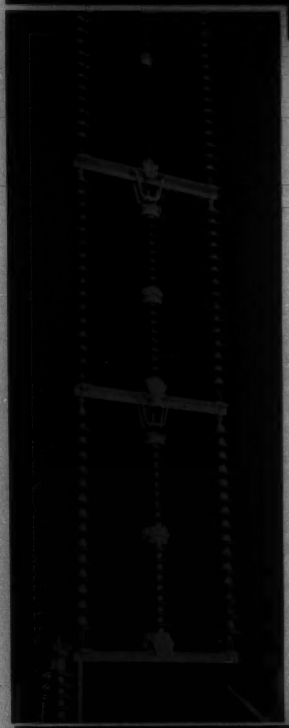
* *Has been published in the* TRANSACTIONS *section of* ELECTRICAL ENGINEERING.



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Through the development of special methods and new highly accurate measuring instruments, Westinghouse engineers have taken the mystery out of lightning and made possible protective devices that have removed much of its menace. So that, today, when lightning strikes, protective action is assured . . . pre-determined by Westinghouse research.

It was the unique facilities of Westinghouse laboratories that made possible the perfection of a porous-block element providing station-type arresters with the low voltage ratio of 2.1. As a result system voltage can safely be held within 2½ times normal . . . even when 10,000 amperes are discharged.

The new Type SV Autovalve station arrester, for 3-kv to 240-kv circuits, can pass 100,000 amperes on a 5–10 microsecond wave. And its special unit-section design permits any arrester rating to be built up to meet individual requirements.

Similar study and research is responsible for many other important Westinghouse achievements . . . each helping to solve some electrical problem for industry, but each overlapping to aid in the perfection of some other Westinghouse apparatus. Thus, within a single organization, you receive the benefits of not one, but a score of developments, to provide you with the most effective and economical solution to any electrical problem. Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pennsylvania

*Above, one of the first photographic records of an actual stroke of lightning on a transmission line, made by Klydonograph, developed by Westinghouse for this purpose. Left, a Westinghouse station arrester unit for Boulder Dam*

**Westinghouse** ENGINEERING RESEARCH FOR INDUSTRY

THE Standards of the American Institute of Electrical Engineers now comprise forty-six sections on electrical machinery and apparatus. They are chiefly devoted to defining terms, conditions, and limits which characterize behavior, with special reference to acceptance tests, and many of them are recognized officially as American Standards.

The Standards available are listed below, together with prices. A discount of 50% is allowed to Institute members (except on Nos. C57.1, 2 and 3). Such discount is not applicable on extra copies unless ordered for other members. Numbers of the Standards Sections should be given when ordering. A binder (illustrated above) for standards is available, with durable, stiff covers, resembling leather, lettered in gold. Price, $1.75 net.

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| **C57.2** | **Test Code for Transformers, Regulators and Reactors (1940)** | |
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Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

## Men Available

ELEC ENGR, Fellow AIEE, professional license varied util, indus exper, U.S. and abroad. Past 15 yrs chief engr, gen supt, util in Mississippi Valley; exper in continuing property records. E-647.

B.S.E.E., Tufts College Engg School, 1940; 24, single; some exper in radio engg. Radio amateur. Desires pos in oprn engg in comn. Location unimportant. Available June, 1940. E-648.

B.S.E.E.; 3 yrs Law, Night, eligible Bar many states; 28, married; 6 yrs pub util comm exper, rates, contracts, valuations, financial, depreciation and cost studies, oprtg problems, regulatory procedure. E-649.

ELEC ENGR, 18 yrs exper des, mfg, sales rotating elec machy. Chief engr several cos. Can handle engg mfg, application and sales. Seeks exec pos in elec or mech industry. E-650.

B.S.E.E., Univ of Utah, 1939; honors, Tau Beta Pi; 25, single; 2 yrs teaching asst physics lab. Desires pos with opportunity for advancement in des or research. Location, salary secondary. E-651-326-Chicago.

E.E., R.P.I., 1928; licensed prof engr, N. Y. 8 yrs coms; 4 yrs X-ray and high voltage rectifiers. Des pos in devpmt or production. Location, New York Metropolitan Area. E-652.

M.S. in E.E., Univ of Minn, 1938; 33, married; 18 mos exper pub util, asst to gen mgr; teaching exper; surveying exper; desires pos with engg future; now employed. E-653-261-Chicago.

B.S.E.E., Col City of New York, recent grad; single. Desires pos with mfr of elec or mech prod. Location immaterial, salary secondary. Available immed. E-654.

INDUS ENGR, 42, married; routing, planning, time study, wage incentive, estimating, mfg, estimating costs. Capable exec, elec and mech. Now employed. E-655.

A.B., E.E., Stanford, 1931, 1933; married; 6 yrs G.E. training including test, generator constr, sales analysis; sales exper including meters, instruments, cables. Desires pos util co, sales or engg, in West. Available immed. E-656.

SM, M.I.T., 1939; B.S.E.E., Univ. of Mich, 1936; 24, married; 2 yrs testg engr high voltage ab; 6 mos research, electronic prod. Desires pos research or des engr in high voltage engg, electronics, comn. Available immed. E-657.

B.E.E.; 30, married; employed in meter dept, util co; 5 yrs exper util, steel mill, draftg, office; util co or mfg pos desired; midwest preferred; Professional Elec Engr, Ohio. E-658.

E.E., SB and SM, M.I.T., 1924; 41, married; 6 yrs tel; 8 yrs des and production engg, mfg; 10 mos state public works; elec des USHA project. Professional license, Conn. E-659.

RECENT GRAD, elec and mech engr; 28, single, ambitious. Desires opportunity for exper leading to responsible engg pos. Interested in sales and production. E-660.

B.S.E.E., W.P.I., 1935; 27, single; 5 yrs prod, inspection, devpmt, leading mfg co. Special studies in sound, vibration. Location, East or N.E. Salary secondary to work with interest and future. E-661.

ELEC GRAD, Pratt Inst, 1934, with some exper in air conditioning eqpt, install and maintenance. Desires pos in same, preferably in East. Available immed. E-662.

B.S.E.E., 1930. Util engg, indus engg and constr, mining electrification and electrician. Interested in connection util, indus organization or mining co. Available short notice. Free to travel. E-663.

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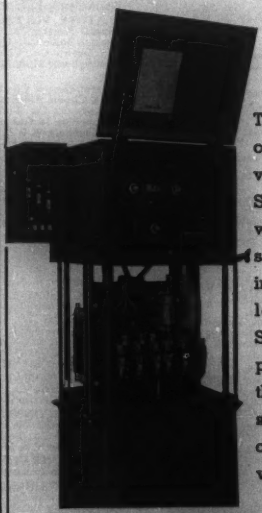

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EVERY DAY many pleasant voices go over the telephone. And it seems to us the number is growing. For most people realize the business and social value of "The Voice with a Smile."

Sometimes what may appear like a gruff or hasty manner is not meant that way at all, but is simply carelessness or thoughtlessness.

Since this is the age of quizzes, how about a short one on some points of telephone usage?

**Do You Talk Directly Into the Telephone?**

The proper way to use the telephone for best results is to hold the transmitter directly in front of the lips while you are talking.

**Do You Speak Pleasantly?**

Remember . . . it may be your best friend or best customer. Greet him as pleasantly as if you were face to face. Pleasant people get the most fun out of life anyway.

**Do You Hang Up Gently?**

Slamming the receiver may seem discourteous to the person to whom you have been talking. You don't mean it, of course, but it may leave the wrong impression.

**Do You Talk Naturally?**

Your normal tone of voice is best. Whispered words are indistinct. Shouting distorts the voice and may make it gruff and unpleasant.

**Do You Answer Promptly?**

Most people do. Delay in answering may mean that you miss an important call. The person calling may decide that no one is there and hang up.

**"The Voice with a Smile"**

can be a real asset. Haven't you often said of some one who has just telephoned — "My, but she has a pleasant voice." Or —"I like to do business with them because they are so nice over the telephone."

It's contagious too. When some one speaks pleasantly to you, it's easy to answer in the same manner.

Many times you form your impression of people—and they judge you — by the sound of a voice over the telephone.

BELL TELEPHONE SYSTEM

THE BELL SYSTEM CORDIALLY INVITES YOU TO VISIT ITS EXHIBITS AT THE NEW YORK WORLD'S FAIR AND THE GOLDEN GATE INTERNATIONAL EXPOSITION, SAN FRANCISCO

## 900,000 Guy Hook Installations—Why?

Why have Electric Light and Power Companies, constituting over half the operating capacity of the U. S. and Canada, placed this M. I. F. line of Through-bolt Guy Hooks on their approved lists? The result has been 900,000 installations in a little over four years, and this is why—or so we are told:

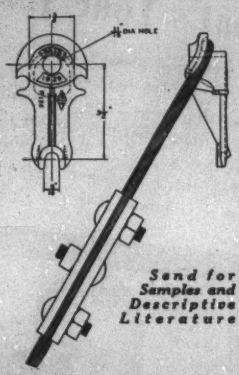
1. *Simplification of Guying Specifications* results from the use of M. I. F. Through-bolt Guy Hooks as they are used with stock through-bolts and lags.

2. *Economical construction* results as the M. I. F. Guy Hook is cheaper than other acceptable through-bolt guying devices developing equal performance under test. Accessory Curved Ribbed Washers, Eye Nuts, Bolt Eyes, and High-strength Thimbleless Eye Anchor Rods are all competitively priced, or better. The durability of these galvanized malleable castings is beyond question.

3. *Safe construction* results from using M. I. F. Guy Hooks. As the guy loop is made up on the ground and then carried up the pole and placed over the Guy Hook retaining ear, protection from contacting live wires is more readily assured. There are no records of failures in service.

4. Proper through-bolt guying leads to no regrets. At least 95% of all sales of 100 or more M. I. F. Guy Hooks have led to consistent repeat orders.

To Transmission and Distribution Engineers, not now using these M. I. F. Guy Hooks and Accessory Through-bolt Guying Devices, we extend an invitation to write for samples *without obligation.*




*Send for Samples and Descriptive Literature*

Misc. M. I. F. Pole Hardware Specialties:—*Williams Pole Mounts—Pole Stubbing Clamps—Aerial Cable Messenger Clamps and Insulated Hangers—Malleable Secondary Racks and Clevises—Tubular Pole Fittings—Transformer Hanger Plates for Through-bolt Mounting—Malleable Crossarm Gains—Screw Anchors—Sidewalk Guy Fixtures and Alley Arm Braces—Crossarm Braces—Guy Strand Payout Reels—Through-bolts, etc.*

**MALLEABLE IRON FITTINGS COMPANY**

Pole Hardware Dept. [ Factory and New England Sales Office ] Branford, Connecticut

New York Sales Office: Thirty Church Street

Canadian Mfg. Distributors:

LINE & CABLE ACCESSORIES, Ltd., Toronto

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in all high impedance circuits use

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Infinite Sensitivity
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Single, Dual and Triple Ranges

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Self-Contained
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RCA BUILDING, NEW YORK, N.Y.


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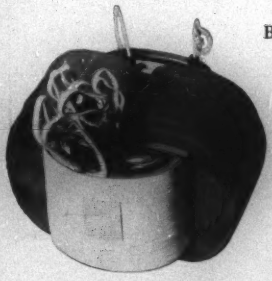
# *What to Look for*

## IN THE UP-TO-DATE TRANSFORMER



BENT IRON CORES, perfected and patented by Kuhlman, are now standard on all Kuhlman Distribution Transformers up to and including 25 kv-a (7,620 volts). This unique core construction utilizes to the fullest extent the most desirable characteristics inherent in improved transformer materials. Because the core material is fluxed parallel to the rolling direction of the steel, permeability is higher and hysteresis is lower. The B. I. Core makes possible a smaller, lighter, easier-to-handle transformer.

PORCELAIN ENAMELED TANKS are furnished upon request, at no additional cost, on all Kuhlman Distribution Transformers up to and including 25 kv-a. The porcelain enamel finish eliminates the havoc of rust and corrosion caused by rain, sleet or snow, thus assuring longer tank life and eliminating the cost of tank maintenance.

STURDY CONSTRUCTION. The entire tank and body of a Kuhlman Distribution Transformer is formed from copper-bearing steel. The top edge is rolled out and forms a perfect gasket seat. The bottom is seam-welded and rolled to provide an extremely strong reinforced base. (Note cut-away sketch). Cover clamps are forged and machined from bronze — no part need be removed in taking off the cover. "Mogul-type" Kuhlman lifting lugs greatly facilitate handling. Rigid steel cover banishes any danger of cover breakage.

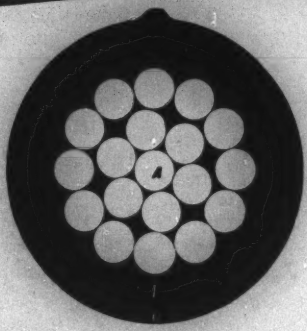
NEW POCKET-TYPE BUSHINGS, both primary and secondary, are now available on all Kuhlman Distribution Transformers from 1½ thru 50 kv-a up to and including 13,200 volts. Pockets are pressed directly into tank body thus entirely eliminating patch pockets or joints. The entrance opening, being recessed, insures gasket protection. The metallic parts of this Kuhlman-developed high voltage bushing are entirely surrounded with porcelain. The simplicity of opening and closing an ordinary valve is incorporated in the mechanical design of this ingenious new bushing. By turning the porcelain knob at the extreme end of the assembly, the clamping mechanism is opened or closed freeing or securely gripping the line connection. The terminal support does not depend exclusively upon the point of contact, but is further supported by the main body of the bushing. In laboratory tests 2,000,000 vibrations were applied without loosening the connection or breaking the wire.

For more complete information about Kuhlman Distribution Transformers, write for catalog No. 40 or for Kuhlman CSP Transformers, catalog No. 340.

*Kuhlman*

KUHLMAN ELECTRIC COMPA

# SEALED INSULATION FROM TERMINAL TO TERMINAL




**A**

*Conductor perfectly centered because insulation and sheath are applied by Okonite's strip-insulating process and vulcanized in a continuous metal mold.*

**B**

*Uniform wall of insulation as determined by service conditions (Okonite, Okolite or Okosheath, as required).*

**C**

*Protective bonded sheath of stable Okoprene—made of neoprene and containing no rubber—resists oil, chemicals, ozone, abrasion, sunlight and is non-inflammable.*

In an Okoprene-sheathed cable, the rubber insulation is permanently sealed right up to the terminal. The vital insulation itself is never exposed to destructive action of air or light. There is no braid that must be cut back to prevent current leakage.

The Okoprene sheath (made of neoprene), is bonded to the insulation during the vulcanizing process and permanently protects it against attack by air, sunlight, ozone, oil or corrosive chemicals.

Okoprene sheaths are unaffected by the range of temperatures encountered under the most exposed conditions and will give long-lived protection to any type of Okonite insulation. Write today for Booklets OK-2009 and OK-2012, The Okonite Company, Passaic, N. J., offices in principal cities.

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**Sheathed Wires and Cables**